US006227853B1

(12) United States Patent
Hansen et al.

(10) Patent No.: US 6,227,853 B1
(45) Date of Patent: May 8, 2001

(54) **MAGNETIC COUPLING SYSTEM AND METHOD**

(75) Inventors: **Thomas T. Hansen**, Ames; **Billy R. Flowers**, Marshalltown, both of IA (US)

(73) Assignee: **Edge Technologies, Inc.**, Ames, IA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/354,611**

(22) Filed: **Jul. 16, 1999**

Related U.S. Application Data

(60) Provisional application No. 60/119,661, filed on Feb. 11, 1999.

(51) **Int. Cl.**^{7} **A61C 1/07**

(52) **U.S. Cl.** **433/119**; 433/147; 279/128

(58) **Field of Search** 433/119, 142, 433/143, 147, 86; 403/DIG. 1; 601/2; 279/128

(56) **References Cited**

U.S. PATENT DOCUMENTS

2,828,131	*	3/1958	Appleby	279/128
2,912,249	*	11/1959	Eckold	279/128
3,007,504	*	11/1961	Clark	279/128
3,256,043	*	6/1966	Krekeler	279/128
3,703,037		11/1972	Robinson .	
3,827,149		8/1974	Brennan .	
3,970,407	*	7/1976	Uffman	279/128
4,080,737		3/1978	Fleer .	
4,207,485		6/1980	Silver	310/104
4,406,621		9/1983	Bailey .	
4,482,034		11/1984	Baermann .	
4,482,829		11/1984	Tardieu et al. .	
4,486,176		12/1984	Tardieu et al. .	
4,515,564		5/1985	Lohn .	
4,964,839		10/1990	Gloor .	
4,995,768	*	2/1991	Craft	279/128
5,013,241		5/1991	von Gutfeld et al. .	
5,219,285		6/1993	Meller et al. .	
5,263,218		11/1993	Giuliani et al.	15/22.1
5,382,162		1/1995	Sharp	433/116
5,451,161		9/1995	Sharp .	
5,567,153		10/1996	Foulkes et al.	433/119
5,865,970		2/1999	Stelter .	
5,886,609		3/1999	Stelter .	
5,915,965	*	6/1999	Uffman	433/118
5,921,562	*	7/1999	Robinson	279/128

OTHER PUBLICATIONS

Moskowitz, L.R., "Classification of Permanent Magnets and Materials", *Permanent Magnet Design and Application Handbook, Second Edition*, Krieger Publishing Company, Malabar, Florida, 11–179, (1995).

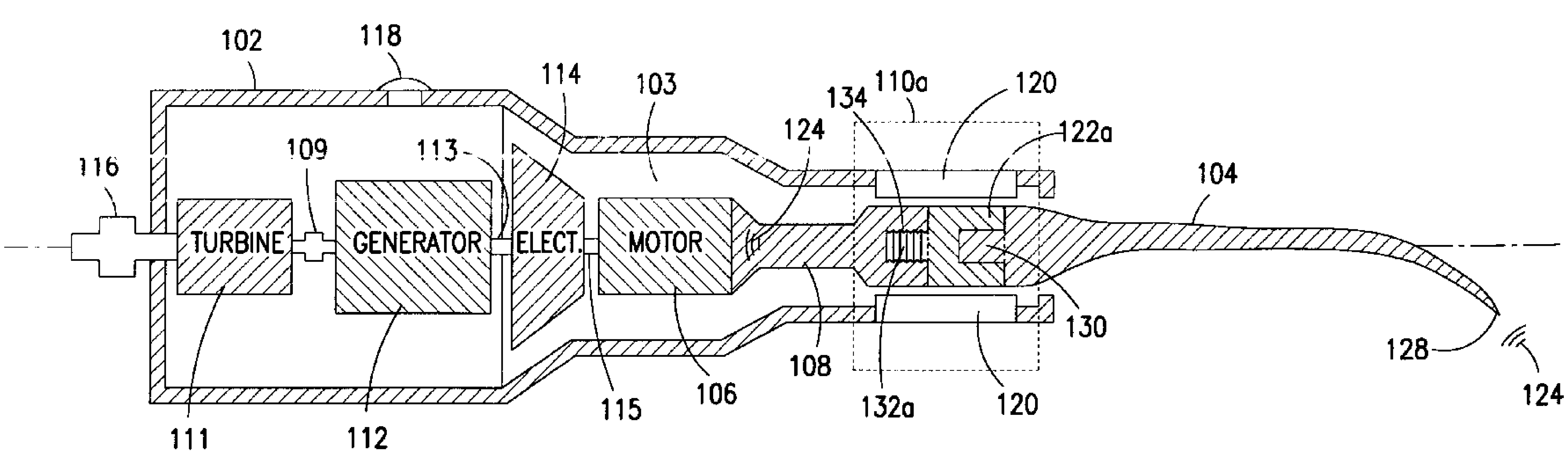
* cited by examiner

Primary Examiner—Todd E. Manahan
(74) *Attorney, Agent, or Firm*—Schwegman, Lundberg, Woessner & Kluth, P.A.

(57) **ABSTRACT**

A magnetic coupling system comprising a magnetic assembly for removably combing a base structure and a tool insert is described. This arrangement allows energy from a transducer located in the base structure to be transmitted through the magnetic assembly to the tool insert. In one embodiment, the magnetic assembly comprises one or more magnetic inserts located between the base structure and tool insert and a permanent magnet or an electromagnet located proximate to the one or more magnetic inserts. The permanent magnet can be axially polarized, radially polarized or polarized at any intermediate angle. In one embodiment, the two components being coupled are a wave guide in direct contact with an ultrasonic motor and a dental scaling tool. In this embodiment, vibrational motion is transferred from the acoustic extension to the tool insert.

51 Claims, 12 Drawing Sheets



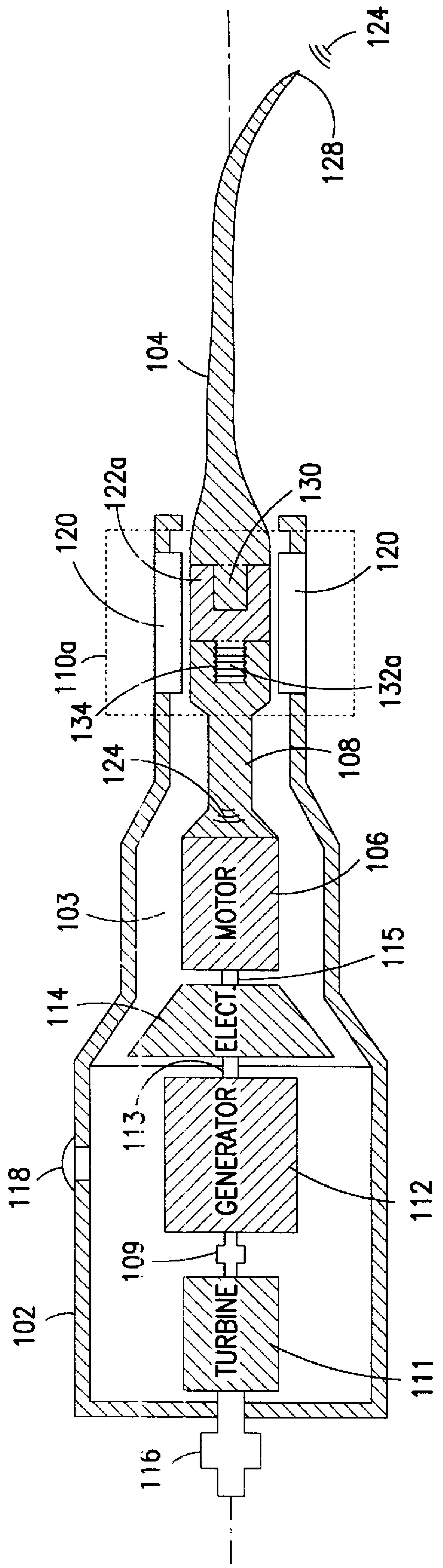

124
128
104
122a
130
120
120
110a
132a
134
124
108
106
MOTOR
103
115
114
ELECT.
113
GENERATOR
118
112
109
102
TURBINE
111
116

FIG. 1A

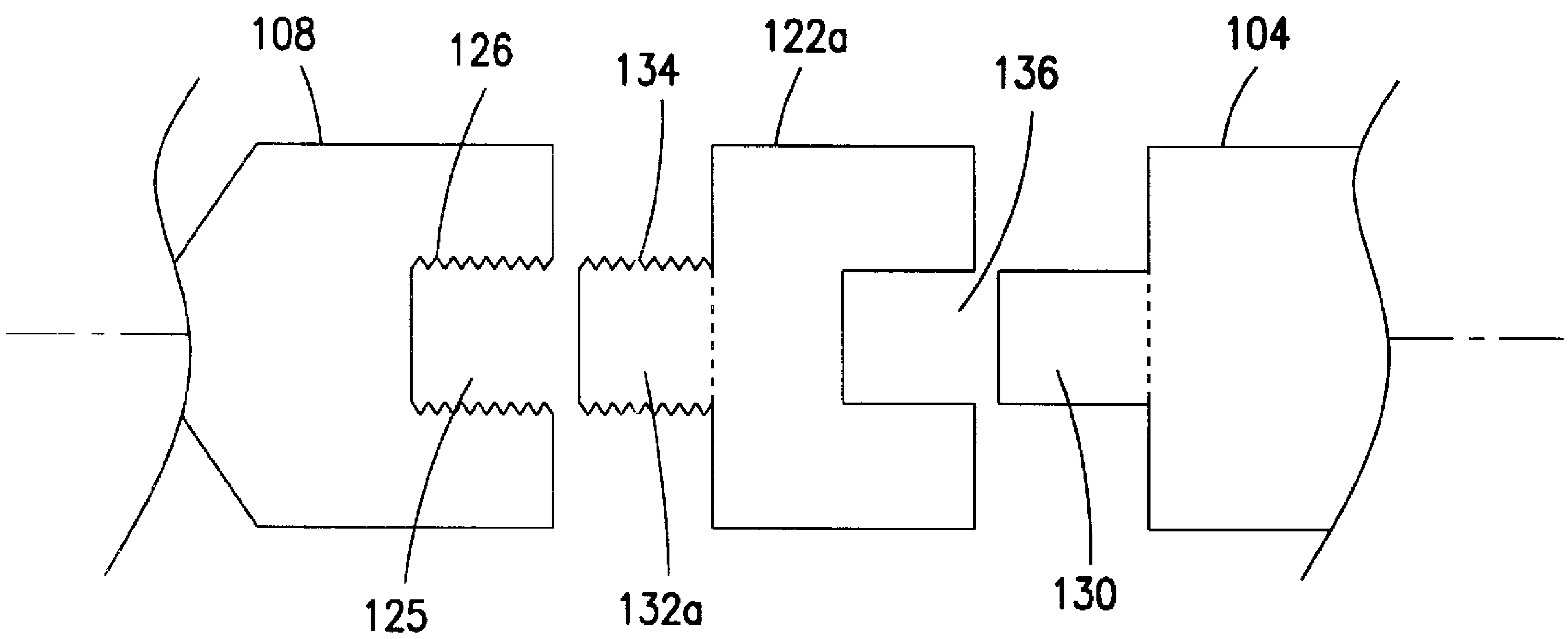


FIG. 1B

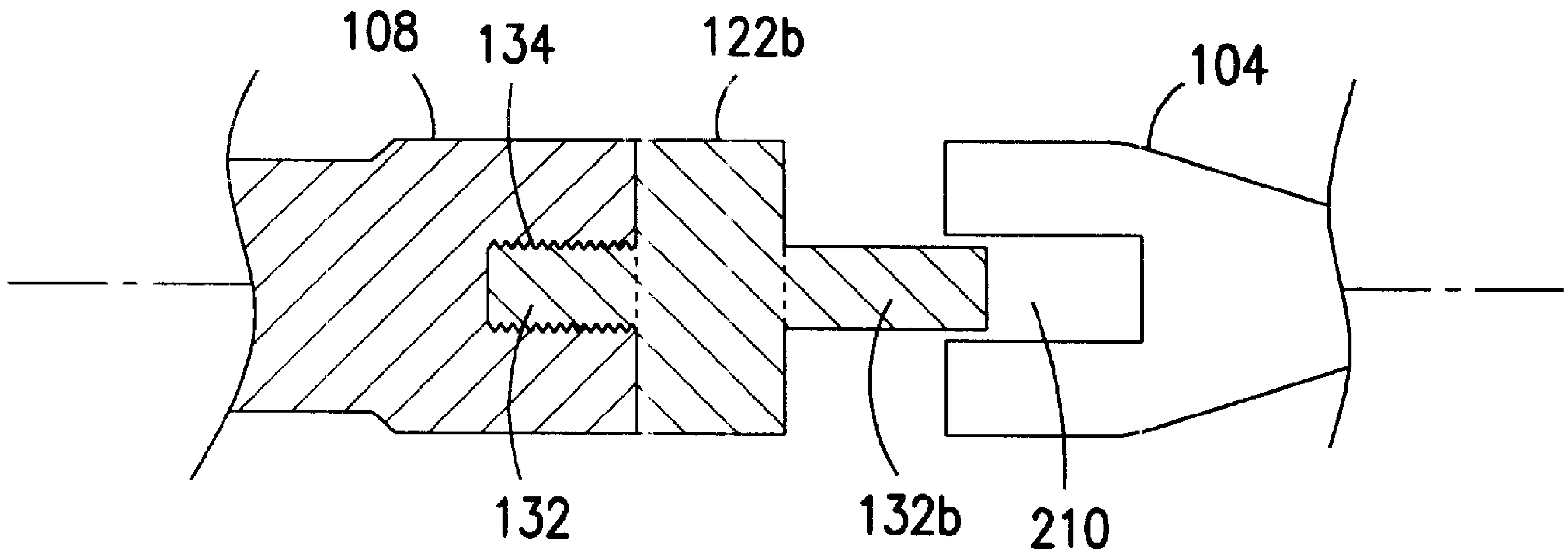


FIG. 2

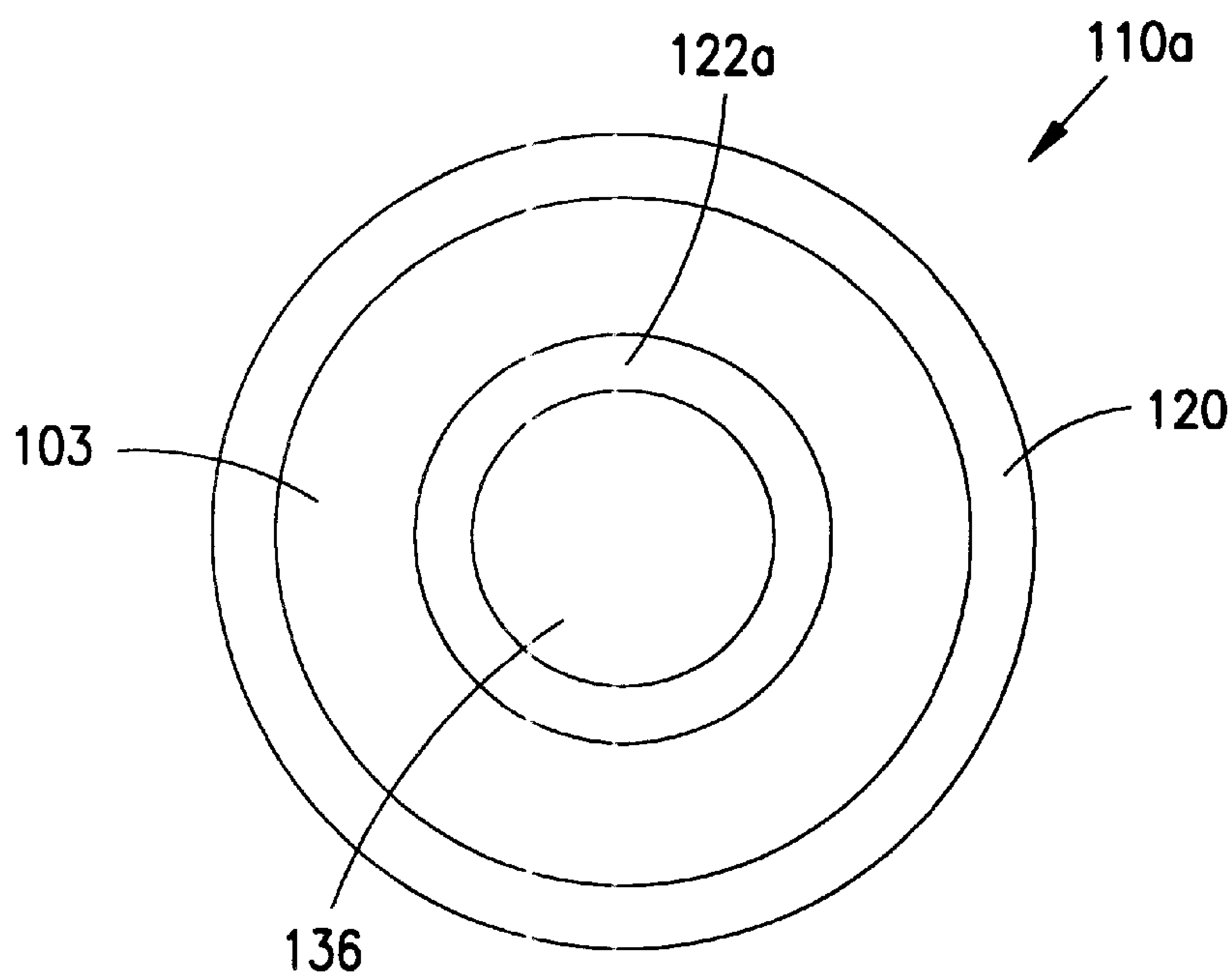


FIG. 3

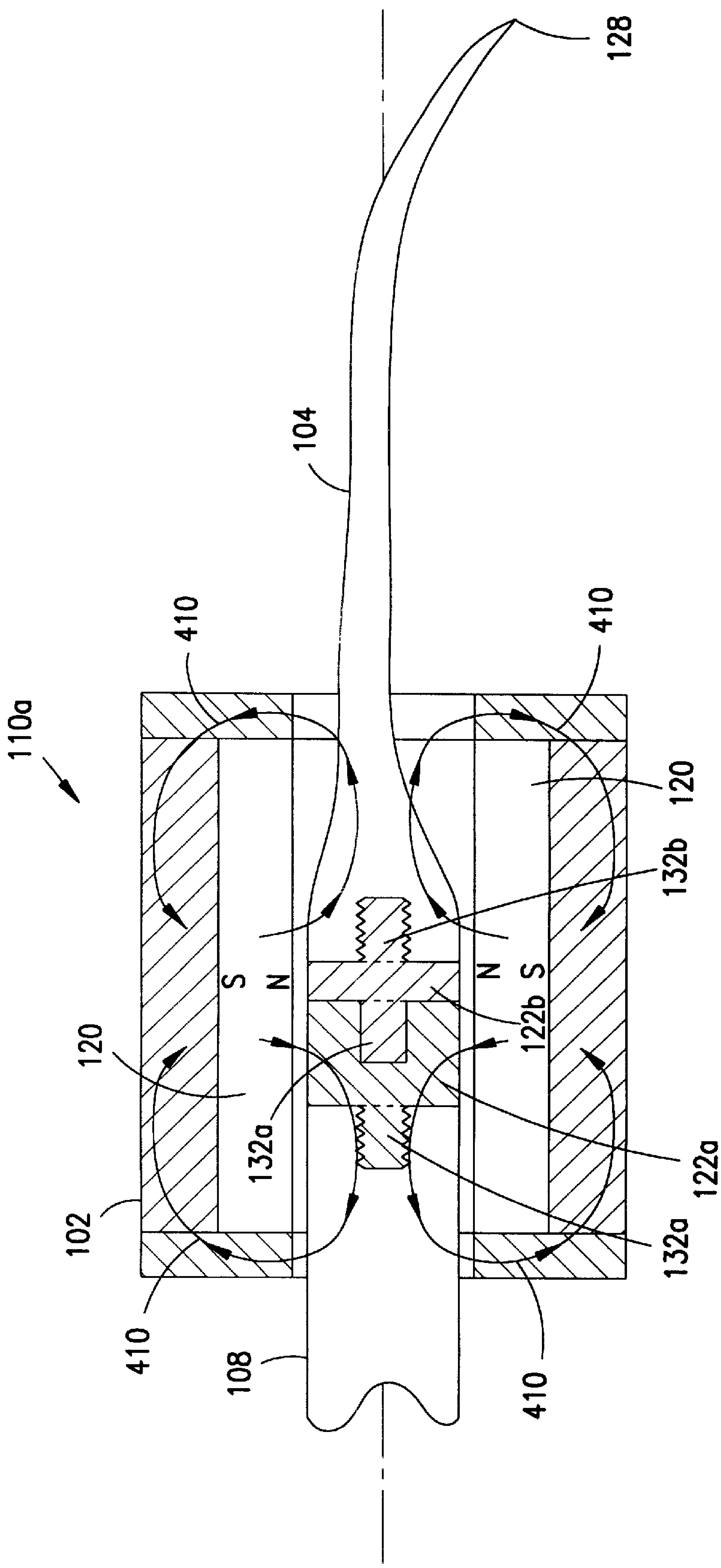

128
104
110a
410
410
120
132b
N S
S N
122b
120
132a
122a
132a
102
410
108
410

FIG. 4

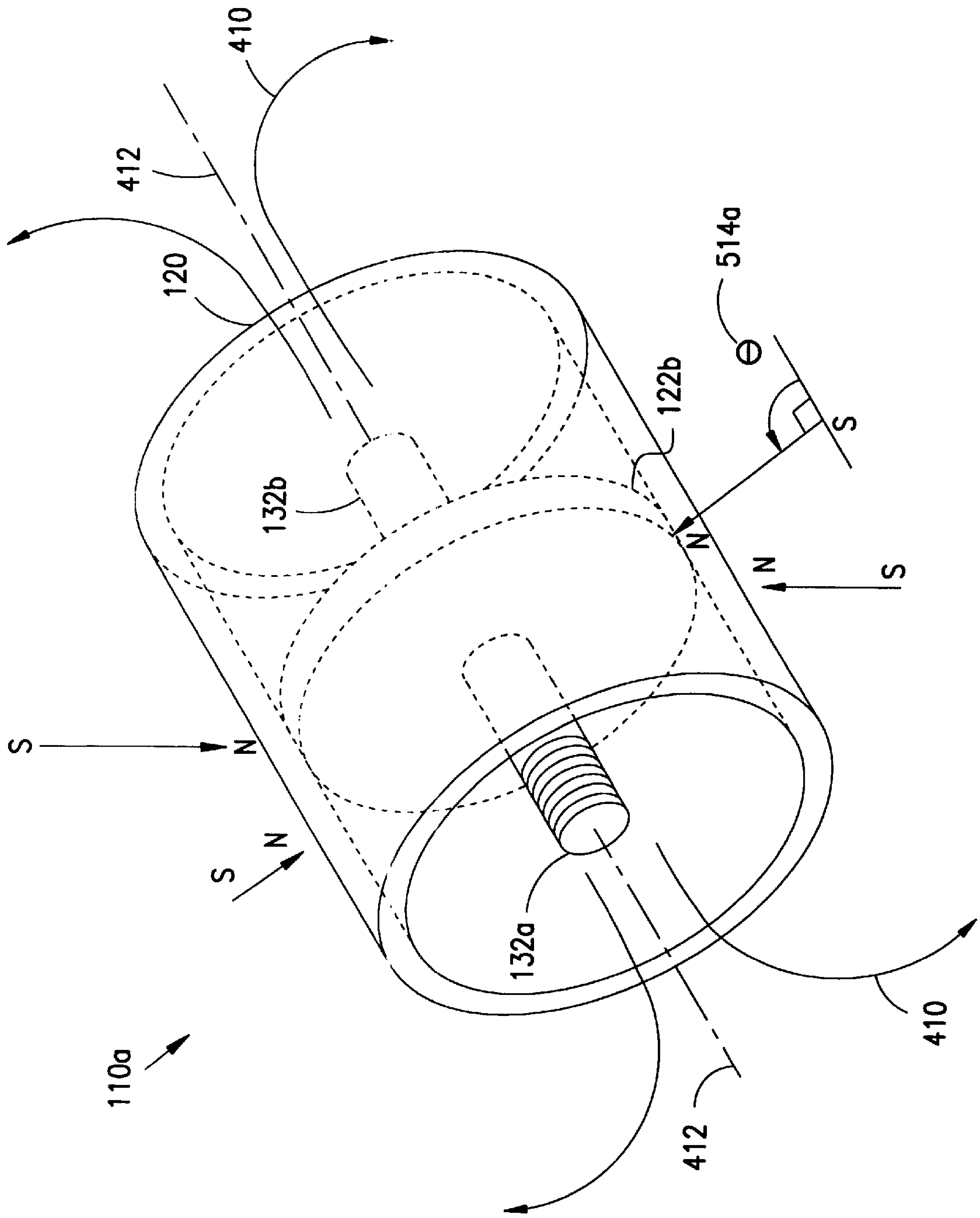


FIG. 5A

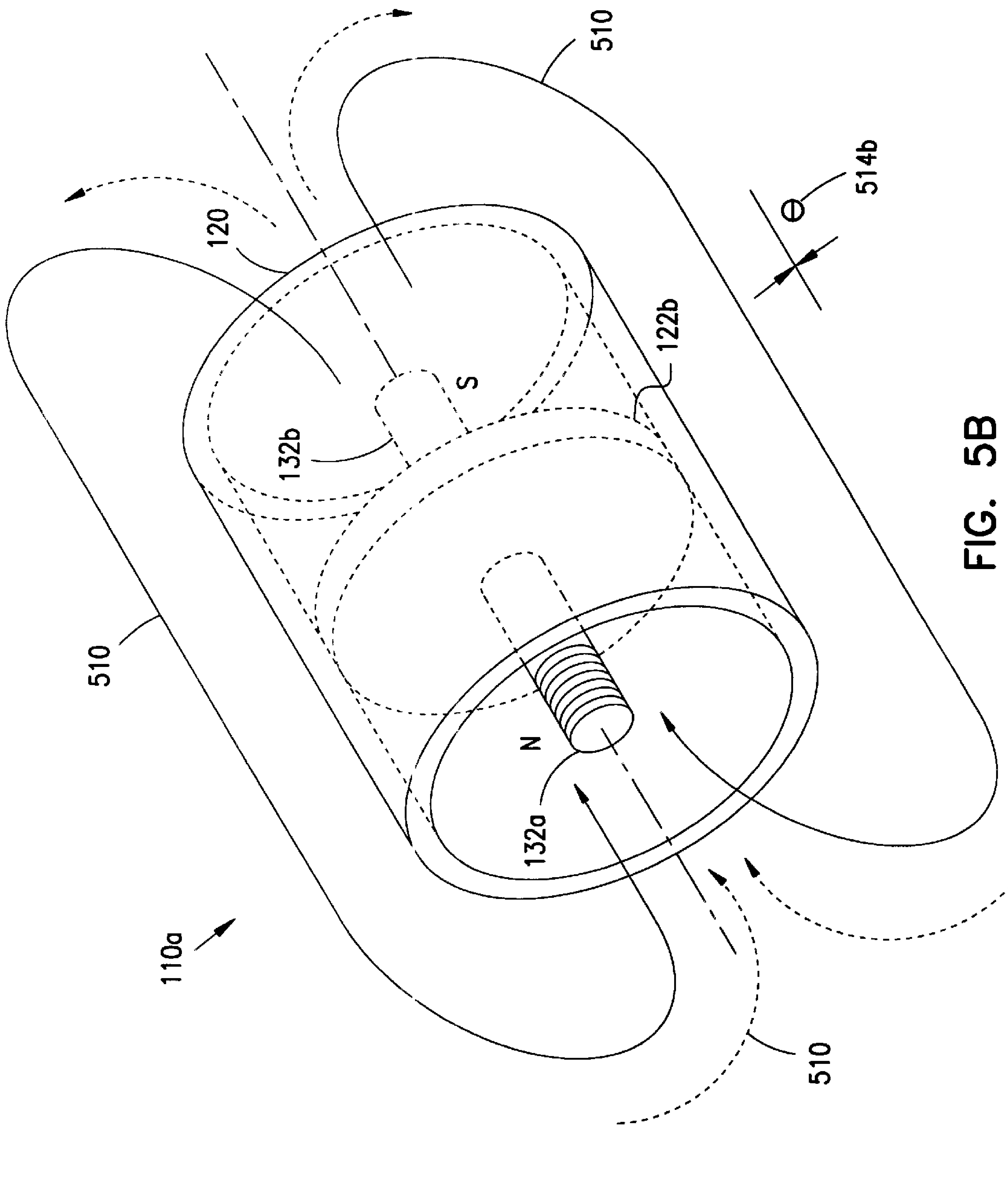


FIG. 5B

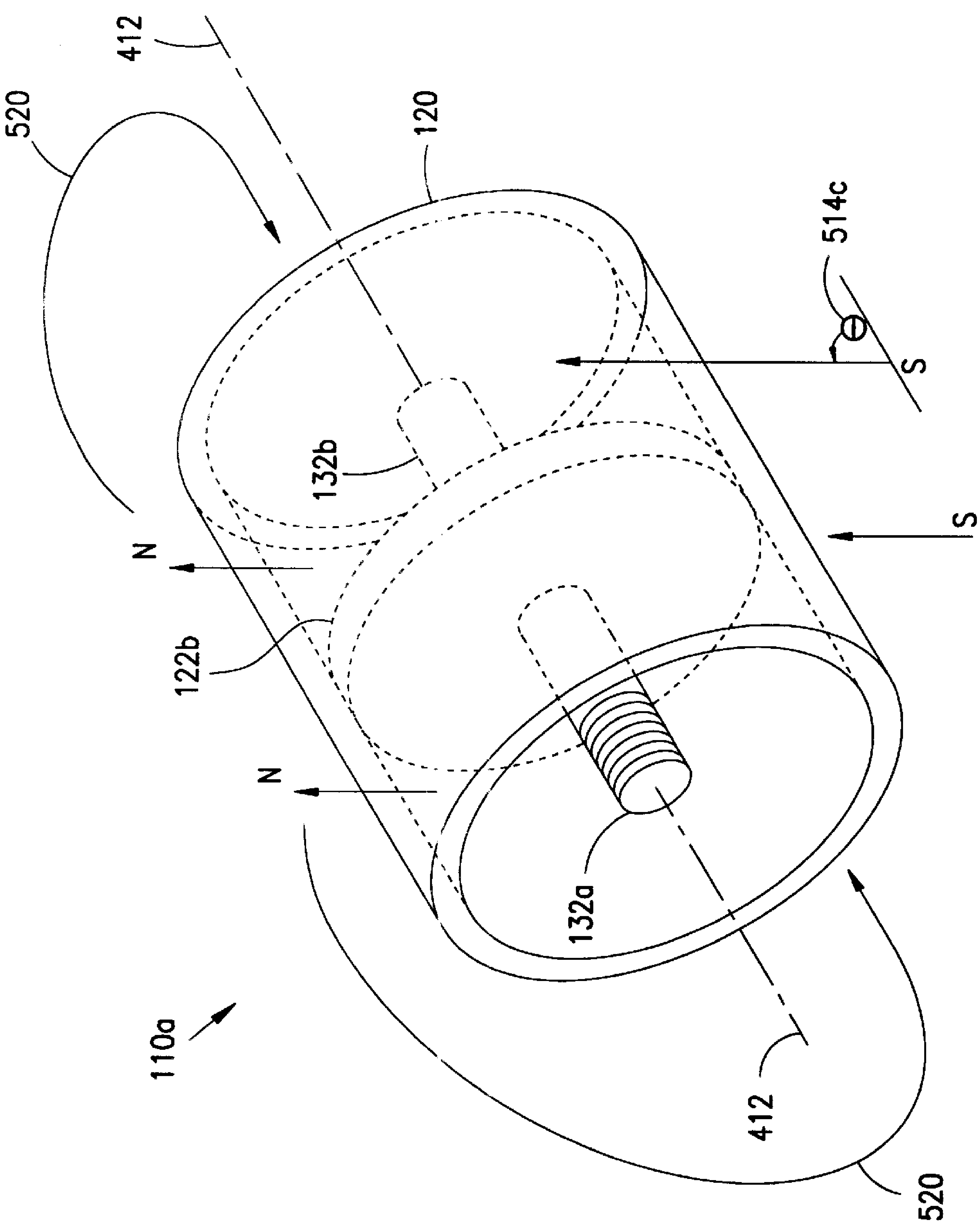


FIG. 5C

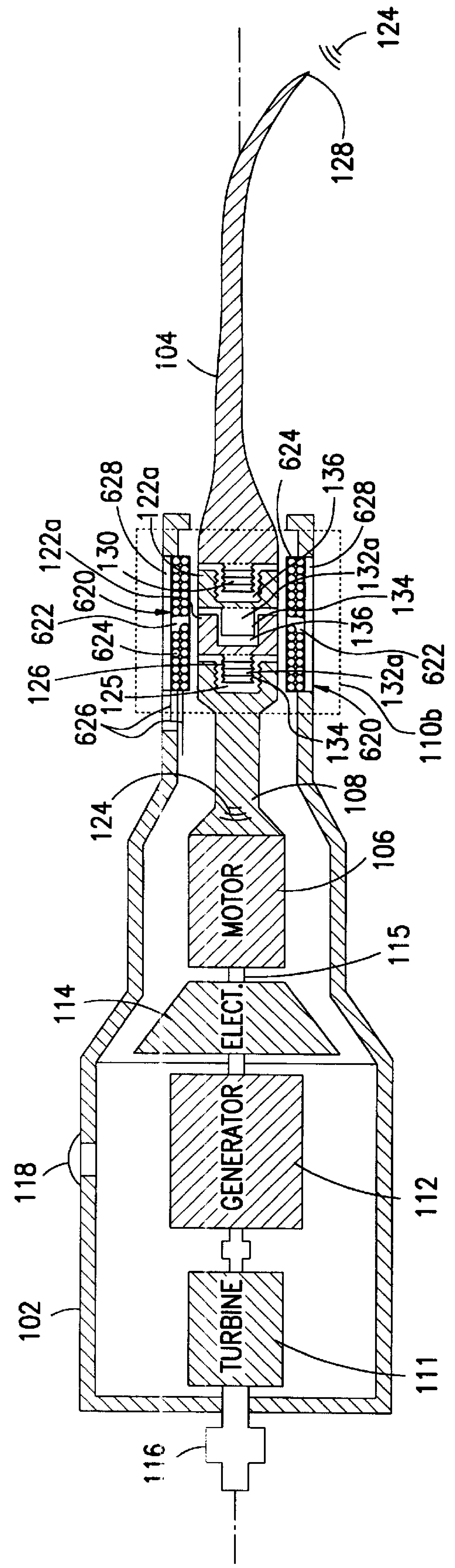

124
128
104
624
136
628
122a
628
130
122a
132a
620
134
622
136
624
622
126
132a
125
626
620
110b
134
124
108
106
MOTOR
115
114
ELECT.
GENERATOR
118
112
102
TURBINE
111
116

FIG. 6

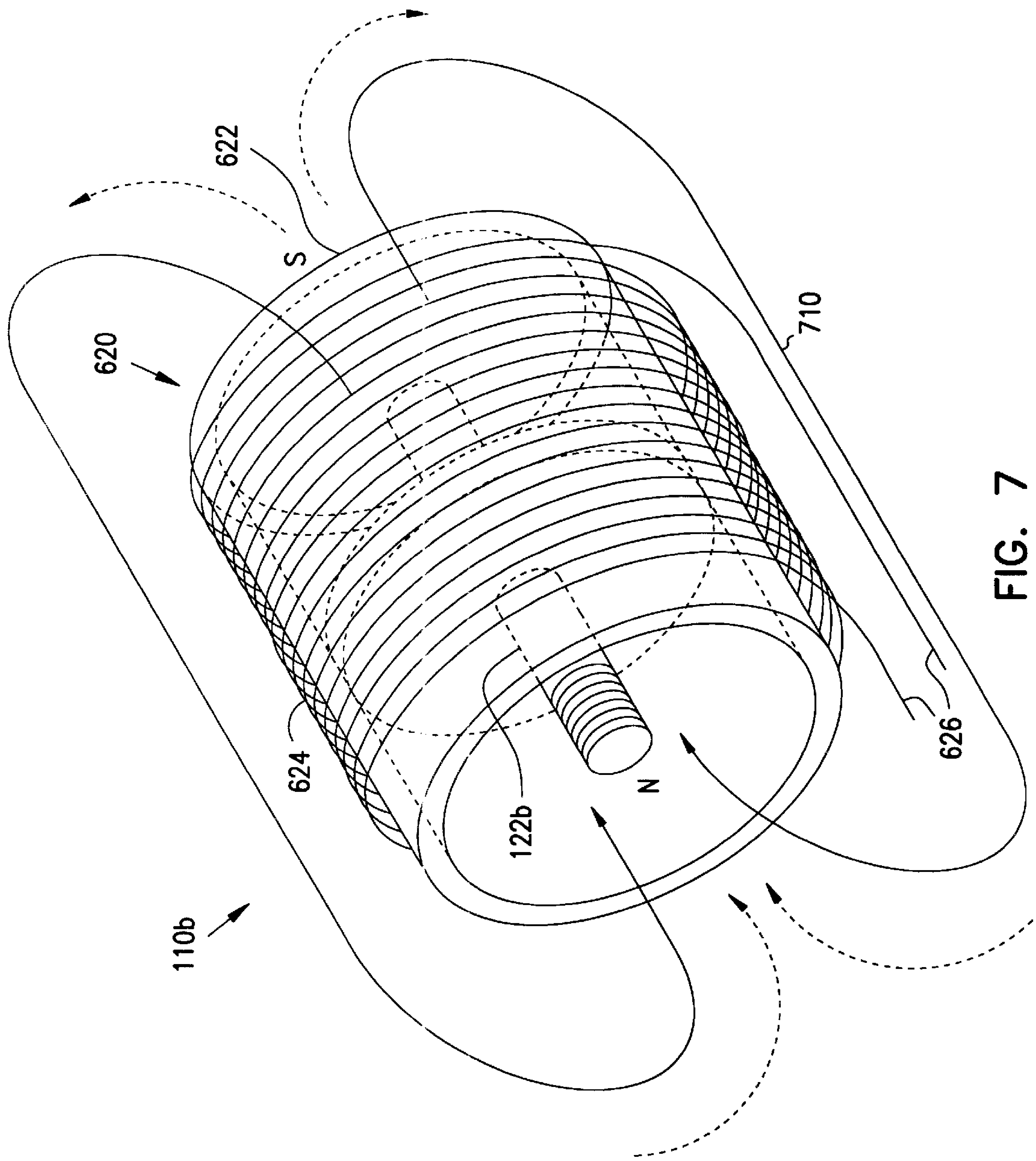


FIG. 7

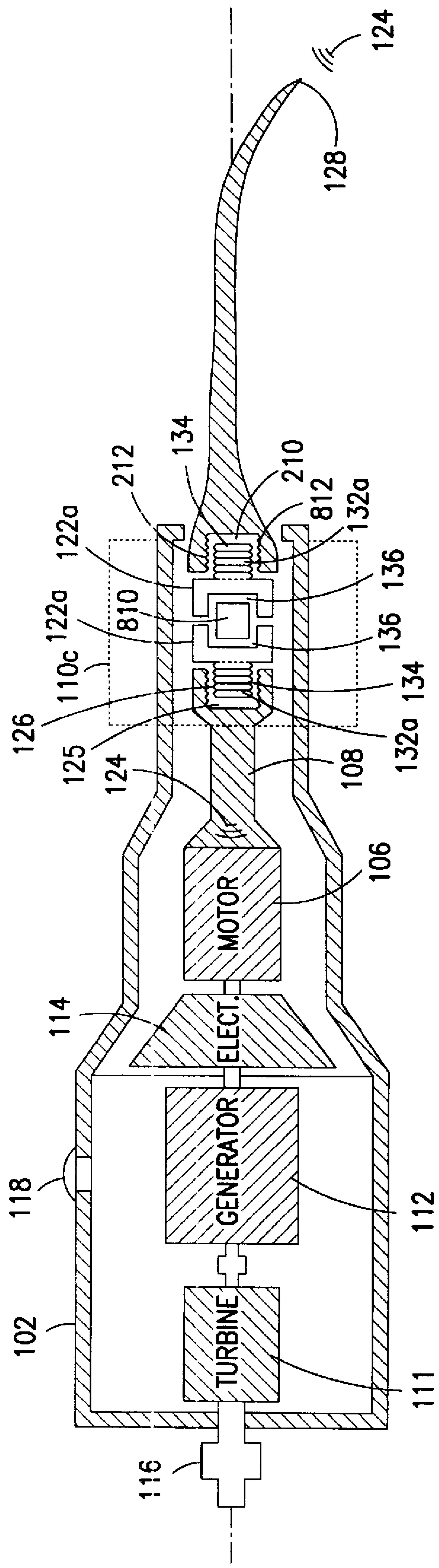

124
128
212
134
210
812
132a
122a
136
810
122a
136
110c
134
126
132a
125
124
108
106
MOTOR
114
ELECT.
GENERATOR
118
112
102
TURBINE
111
116

FIG. 8

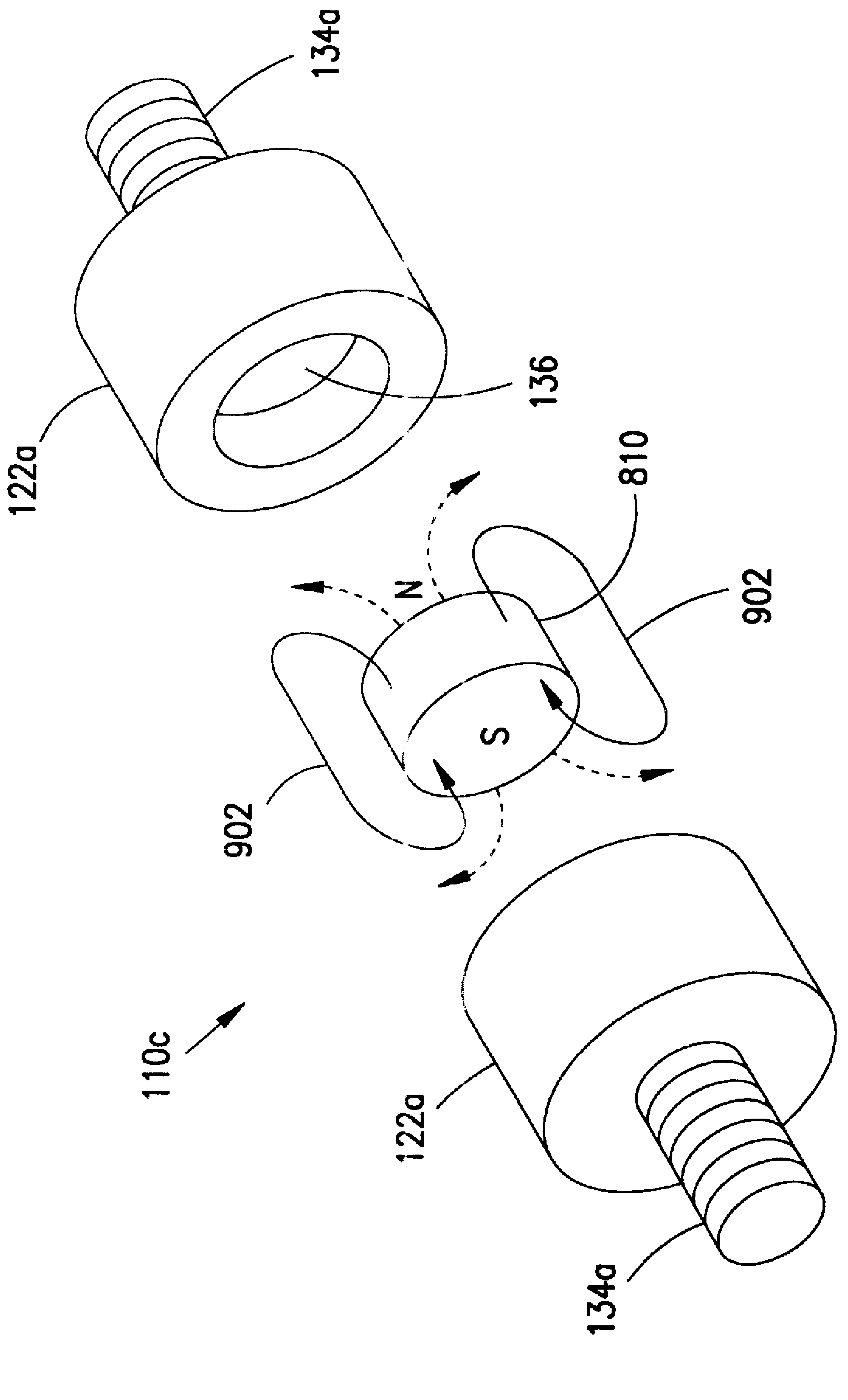


FIG. 9

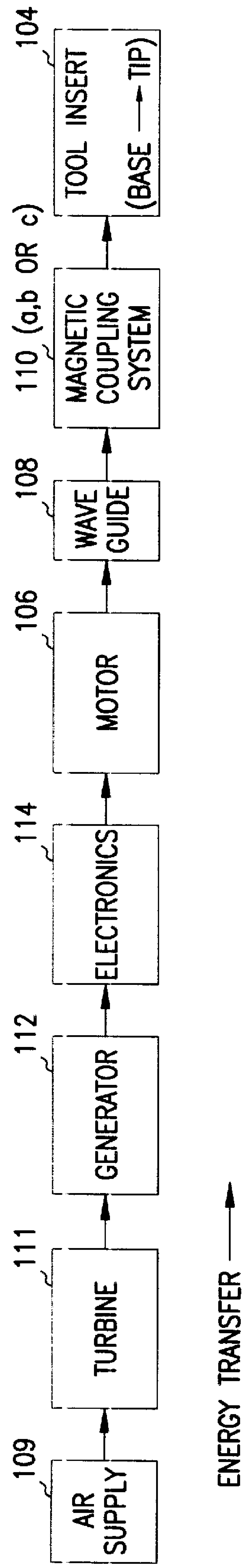

AIR SUPPLY
109
TURBINE
111
GENERATOR
112
ELECTRONICS
114
MOTOR
106
WAVE GUIDE
108
MAGNETIC COUPLING SYSTEM
110 (a,b OR c)
TOOL INSERT
(BASE → TIP)
104
ENERGY TRANSFER

FIG. 10

MAGNETIC COUPLING SYSTEM AND METHOD

This application claims the benefit under 35 U.S.C. 119 (e) of U.S. Provisional Application No. 60/119,661 filed on Feb. 11, 1999.

FIELD

This invention relates generally to coupling systems, and in particular the present invention relates to detachable coupling systems.

BACKGROUND

Coupling mechanisms or systems are used in a variety of devices to join various types of tools, such as drill bits, dental implements, etc., to a base structure, such as a transducer. Some coupling systems are also used to transmit torque from one component to another. Many of these coupling systems are intended to be relatively permanent, such that the joints are welded or soldered, as with hot plate welding and ultrasonic assembly. However, this type of arrangement lacks flexibility, since the user does not have the ability to use the same base structure with other tools. Further, since replacement of the tool also includes replacement of the base structure, this type of coupling system can be costly.

Detachable coupling systems, such as screw threads or latches, are designed to removably combine components. However, such designs can lead to galling or thread wear. Known detachable coupling systems which are magnetic are often relatively complex in their design and are typically used to transmit or resist torque. In the dental field, the coupling of sonic energy from a transducer to a liquid stream using a magnetostrictive rod is known, although due to the poor acoustic impedance match between solid and liquids, such transmission is relatively poor, or less than about 20%.

Therefore, what is needed is a simple detachable coupling system that efficiently transmits energy from a transducer to an attached tool.

SUMMARY

A magnetic coupling system comprising a magnetic assembly for removably combing a base structure and a tool insert is described. This arrangement allows energy from a transducer located in the base structure to be transmitted through the magnetic assembly to the tool insert. In one embodiment, the magnetic assembly comprises one or more magnetic inserts located between the base structure and tool insert and a permanent magnet or an electromagnet located proximate to the one or more magnetic inserts.

The permanent magnet can be polarized in any suitable manner, such as axially or radially or at any intermediate angle. In one embodiment, the permanent magnet or electromagnet is cylindrical in shape and surrounds the one or more magnetic inserts. In another embodiment, the permanent magnet is located between two magnetic inserts.

In an exemplary embodiment, the two components being coupled are a wave guide in direct contact with an ultrasonic motor and a dental scaling tool. In this embodiment, vibrational motion is transferred by the magnetic coupling system from the wave guide to the tool insert. If desired, the components are arranged such that the vibrational motion is transformed to flexural or elliptical motion at the tip of the tool insert.

The magnetic coupling system transfers energy efficiently and provides a firm connection during use. It gives the user

the ability to quickly remove and attach implements as needed. The system is simple, inexpensive, and provides reliability by eliminating problems such as galling and thread wear.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**A is a cross-sectional view of a dental tool with a magnetic coupling system having a cylindrical permanent magnet in one embodiment of the present invention.

FIG. **1**B is an enlarged cross-sectional partial view of a magnetic insert in between two mating parts in one embodiment of the present invention.

FIG. **2** is an enlarged cross-sectional partial view of an alternative magnetic insert in between two mating parts in one embodiment of the present invention.

FIG. **3** is an end view of a magnetic coupling system in one embodiment of the present invention.

FIG. **4** is a cross-sectional partial view of a dental tool having a magnetic coupling system with a cylindrical permanent magnet which is radially polarized in one embodiment of the invention.

FIGS. **5**A, **5**B and **5**C are simplified perspective illustrations of the magnetic coupling system shown in FIG. **1**A with the corresponding flux lines showing radial polarization, axial polarization and intermediate radial polarization, respectively.

FIG. **6** is a cross-sectional partially expanded view of a dental tool with an alternative magnetic coupling system having an electromagnet in one embodiment of the present invention.

FIG. **7** is a simplified perspective illustration of the alternative magnetic coupling system shown in FIG. **6** with the corresponding flux lines showing axial polarization.

FIG. **8** is a cross-sectional partially expanded view of a dental tool with another alternative magnetic coupling system having a permanent magnet located between two magnetic inserts in one embodiment of the present invention.

FIG. **9** is an exploded view of the alternative magnetic coupling system shown in FIG. **8** with the corresponding flux lines showing axial polarization.

FIG. **10** is a flow diagram showing components through which energy can be transferred in one embodiment of the present invention.

DETAILED DESCRIPTION

In the following detailed description, reference is made to the accompanying drawings which form a part hereof, and in which is shown by way of illustration specific embodiments in which the inventions may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the invention, and it is to be understood that other embodiments may be utilized and that mechanical, procedural, electrical and other changes may be made without departing from the spirit and scope of the present inventions. The following detailed description is, therefore, not to be taken in a limiting sense, and the scope of the present invention is defined only by the appended claims, along with the full scope of equivalents to which such claims are entitled.

The system described herein provides means for mechanically coupling two components together using a magnetic assembly. The magnetic assembly holds the two components firmly together in the presence of a magnetic field so that energy, such as kinetic energy, can be passed from one component to the other. The magnetic means can be used with various transducers, such as ultrasonic or sonic motors, and a variety of tools, such as dental ultrasonic scalers.

FIG. **1A** shows a cross-sectional view of one embodiment of the present invention comprising a magnetic coupling system **110***a* within a handpiece **102** (having a handpiece cavity **103**) which is coupled to a tool insert **104**. The handpiece cavity **103** contains a motor **106**, a wave guide **108** and the magnetic coupling system **110***a* The handpiece **102** also contains a turbine **111**, a generator **112** and electronics **114**, which are discussed further in FIG. **10**. A turbine-generator connector **109** is located between the turbine **111** and generator **112**, a generator-electronics connector **113** is located between the generator and the electronics **114**, and a electronics-motor connector **115** can be located between the electronics **114** and the motor **106**. In an alternative embodiment, there is no electronics-motor connector **115**, and the electronics **114** and motor **106** are integral with each other or are otherwise modified to be directly connected. An air connector **116** as is known in the art is connected to the handpiece and a conventional power adjustment switch **118** is located on top of the handpiece **102**. In the embodiment shown in FIG. **1A**, the magnetic coupling system **110***a* comprises a permanent magnet **120** and an open-ended magnetic insert **122***a*.

The handpiece **102** can be any conventional handpiece designed for a particular application. In the embodiment shown in FIG. **1A**, the handpiece **102** encloses the handpiece cavity **103** which contains all of the components located between, and including the turbine **111** and the magnetic coupling system **110***a*. In an alternative embodiment, the magnetic coupling system **110***a* extends beyond the end of the handpiece **102**. The handpiece **102** can be made from any suitable material. In one embodiment, the handpiece **102** is made from plastic. In another embodiment, a hard plastic known as Ultem™ made by GE Plastics in Pittsfield, Mass. is used.

The magnetic coupling system **110***a* is used to detachably couple two mating parts and to transfer energy from one of the mating parts to the other. In the embodiment shown in FIG. **1A**, the "mating parts" are the wave guide **108** and the tool insert **104**. The wave guide **108** is an acoustic extension which transmits sound waves produced by the motor **106**. In one embodiment, the wave guide **108** increases the amplitude of these sounds waves, and as such, can also be referred to as a "horn." The tool insert **104** is essentially a horn which is coupled to the wave guide **108** at one end, transferring energy to the tip **128** of the tool insert **104**. (The term "horn" is generally understood in the art to be a component used to increase the amplitude of sound waves, such that both the wave guide **108** and tool insert **104** can be considered "horns" in certain embodiments. For clarity, however, the terms "wave guide" and "tool insert" will be used throughout this application to refer specifically to components **108** and **104**, respectively).

The wave guide **108** and tool insert **104** can both be made from any suitable material, but do not necessarily need to be made of the same material. It is known that the speed at which sound travels through a material is related to several factors including, but not limited to, its temperature, modulus of elasticity, density, Poisson's ratio, and so forth. In one embodiment the material used for the wave guide **108** and tool insert **104** is a very low damping (high quality factor {Q}) nonmagnetic material, although the invention is not necessarily so limited. The damping capacity of a material decreases in accordance with decreasing elastic hysteresis. As a result, materials with low elastic hysteresis, or materials having a relatively low density, such as aluminum, magnesium or titanium, with densities of about 1.8 to 4.8 gram/cubic centimeter (g/cc), demonstrate a relatively high vibration amplitude output velocity, which can be expressed as a vibration output of one unit of displacement. Conversely, and in accordance with the conservation of momentum principle, high density materials, such as stainless steel and tungsten, having densities of about 7.5 to 18.5 g/cc, limit the net amplitude which can be produced by a component, such that the transfer of vibrations through the material is decreased to about one-fifth to one-half unit of displacement.

Since velocity is proportional to frequency times amplitude, the actual velocity or vibration output is also dependent on the type of motor used. Therefore, for a given motor frequency, when the density of the wave guide material is doubled, the velocity of the output for the wave guide **108** is typically reduced by about one-half. In one embodiment, the density of the material used for the wave guide **108** and tool insert **104** is about four (4) to 4.8 g/cc. In another embodiment, the material has a "Q" greater than about 100 and a fatigue strength ranging from about 12,420 to 96,600 MPa (about 18,000 to 140,000 psi).

Examples of materials which can be used include, but are not limited to, acoustic metals such as aluminum, magnesium, titanium and alloys of these metals. This includes materials which are of various American Society for Testing and Materials (ASTM) types as described on page 9 in U.S. application Ser. No. 08/855,228 (hereinafter "U.S. application") filed on May 13, 1997 and owned by the same Assignee as this application, which is hereby incorporated by reference in its entirety. (See also PCT International Patent Application No. PCT/US98/09848 (hereinafter "PCT Application") deposited on May 11, 1998 and also owned by the same Assignee as this application, which is hereby incorporated by reference in its entirety).

The wave guide **108** and tool insert **104** can also be made from magnetic materials. In one embodiment, any of the approximately 70 standard types of ferromagnetic stainless steel or steel alloys are used. These steels are produced in "wrought form" American Iron and Steel Institute (AISI) types and as "cast alloy" Alloy Casting Institute (ACI) types. Generally, all of these materials are iron-based, although some, such as the 300 series stainless steel, are so low in iron as to be considered non-magnetic. These steels or steel alloys also contain about 12 to 30 percent chromium, about zero (0) to 22 percent nickel, and minor amounts of carbon, columbium, copper, molybdenum, selenium, tantalum and titanium. Examples of materials which can be used include, but are not limited to 420 stainless steel, 18-4 stainless steel, 17-4 PH precipitation-hardening stainless steel, and so forth. In another embodiment, carbon steels and certain nickel-based alloy steels are used. A steel wave guide **108** may be preferable in powder metallurgy applications where work is being performed on very stiff, high acoustic impedance materials, such as tungsten. In another embodiment, the wave guide **108** is made from a nonmagnetic material as described above and the tool insert **104** is made from a magnetic material. In a specific embodiment, the wave guide **108** is made from titanium and the tool insert **104** is a dental tool made from 420 stainless steel.

As noted above, the wave guide **108** transmits sounds waves from a transducer, such as a motor. In the embodiment shown in FIG. **1A**, the wave guide **108** interacts directly with the motor **106** and transmits energy from the motor **106** to the tool insert **104**. In one embodiment, vibrations **124**, i.e., vibrational motion, is transferred through the wave guide

108 and across the magnetic coupling system **110***a* to the tip **128** of the tool insert **104** as shown. Vibrational motion can also be transformed to flexural or elliptical motion at the tip **128**, when the tool insert **104** is aligned off-center in relation to the other components. Such motion can be desirable for certain applications with a dental scaler, for example. In an alternative embodiment, a non-steady or pulsing energy is transferred. In yet another alternative embodiment, more than one wave guide **108** is used. However, adding additional wave guides **108** can cause additional power losses, and at some point, it is not efficient or practical to add more wave guides **108**. In one embodiment, two (2) to four (4) wave guides **108** are used. In an alternative embodiment, there is no wave guide **108**, and the motor **106** transmits energy through the magnetic coupling system **110***a* to the tool insert **104**.

The wave guide **108** can be any suitable size and shape depending on the particular application. For example, in the embodiment shown in FIG. **1**A, the wave guide **108** is intended to be part of a hand held tool, and is designed to be a convenient and comfortable size for performing detailed work. In one embodiment, the wave guide **108** is about one-half the size of the tool insert **104**. The size of the wave guide **108** is also dependent on the desired frequency being generated by the motor **106**. In general, the higher the frequency, the smaller the length of wave guide **108** which is required. In one embodiment, the wave guide is about 0.4 to 1.7 cm (about 0.16 to 0.7 in) in diameter and about 2.5 to ten (10) cm (about one (1) to 3.9 in) in length. In a particular embodiment, the wave guide **108** is about five (5) cm (about two (2) in) long.

In an alternative embodiment, the diameter of the wave guide **108** is larger than about 1.9 cm (about 0.75 in) up to about nine (9) cm (about 3.5 in) or more in diameter or length. When the diameter of the wave guide **108** is large, such as greater than about nine (9) cm (about 3.5 in), side motion and transient frequencies can alter the amplitude at the interface of the tool insert **104** and create internal stress. A wave guide **108** of this size may be needed when the tool insert **104** has a large diameter. In one embodiment, one or more suitably-designed slots are machined into the sides of the wave guide **108**. The use of slots effectively divides the wave guide **108** into smaller, individual wave guides **108**, ensuring uniform amplitude and relieving internal stresses, thus reducing transverse vibrations. Large wave guides **108** can also be used with a motor **106** having a power output of about 25 kW or more.

The wave guide **108** and motor **106** can be coupled together in any suitable way. In one embodiment, the wave guide **108** is a solid, cylindrically-shaped object which can be designed to fit together with other components as needed. In the embodiment shown in FIG. **1**A, the cylindrically-shaped wave guide **108** flares out at the end adjacent to the motor to be contiguous with the motor **106**. In a particular embodiment, the wave guide **108** and motor **106** are manufactured as one unit. In an alternative embodiment, the wave guide **108** does not flare out at the motor end, but is still contiguous with the motor **106**. In another alternative embodiment, the wave guide **108** is connected to the motor in any suitable manner such as with threads, welding, press fitting, and so forth.

In the embodiment shown in FIG. **1**A, the opposing or coupling end of the wave guide **108** also flares out, although this is not necessary for the invention, as long as the two mating parts (wave guide **108** and tool insert **104**) can be adequately coupled together. Similarly, the exact size and shape of the tool insert **104** is not important, as long as the mating end of the tool insert **104** can be joined with the open-ended magnetic insert **122***a* or to the mating end of the wave guide **108**, if no open-ended magnetic insert **122***a* is used. Depending on the particular design, a variety of tool inserts **104** can be used. In one embodiment, the tool insert **104** is any type of tool used to perform work such as a dental tool, knife blade, surgical instrument, chemical applicator, drill bit, and so forth. In the embodiment shown in FIG. **1**A, the tool insert **104** is a dental scaler having a tip **128** on one end. The mating end of the tool insert **104** has a tool insert stub **130** and is essentially a "male" end which couples with the open-ended magnetic insert **122***a* as described below. In one embodiment, the tip **128** has a diameter of about 0.05 mm (0.002 in) and the tool insert stub **130** has a diameter of about 0.64 cm (0.25 in). In an alternative embodiment, the tool insert **104** has two or more tips **128**. For example, a dental scaler can be combined with a lavage tip for dispensing water through or over the surface of the scaler tip.

As noted above, the magnetic coupling system **110***a* shown in FIG. **1**A comprises one open-ended magnetic insert **122***a* and the permanent magnet **120**, although the design is not so limited. Any suitable number and type of magnetic insert can be used, and does not necessarily need to be open-ended on one end. The magnetic insert can have two open ends or can have two stubs as described in FIG. **2**. Typically, one magnetic insert is used when one of the mating parts, i.e., the wave guide **108** or tool insert **104**, is nonmagnetic. Two or more magnetic inserts are typically used if both mating parts are nonmagnetic. In an alternative embodiment, both mating parts are magnetic and no magnetic inserts are used.

In the embodiment shown in FIG. **1**A, the open-ended magnetic insert **122***a* has a "male" end and an opposing "female" end. The "male" end, or magnetic insert stub **132***a*, has stub threads **134** and is designed to couple with the wave guide cavity **125** which has wave guide cavity threads **126** located around its circumference, as shown in FIG. **1**B. Similarly, the opposing "female" end of the open-ended magnetic insert **122***a* forms a magnetic insert cavity **136** as shown in FIG. **1**B and is designed to couple with a male component, such as the tool insert stub **130**. Any suitable tolerance between the magnetic insert cavity **136** and the male component can be used, such as about 0.025 mm to 0.125 mm (about 0.001 to about 0.005 in).

The wave guide **108**, open-ended magnetic insert **122***a* and tool insert **104** are joined together by inserting the magnetic insert stub **132***a* into the wave guide cavity **125** and screwing the two components together. The tool insert stub **130** is inserted, but not screwed, into the open end of the open-ended magnetic insert **122***a*, i.e., the magnetic insert cavity **136**. When combined with the use of an attractive magnetic force as provided by the permanent magnet **120**, such an arrangement provides a firm connection between the components, as shown in FIG. **1**A, and reduces or eliminates sliding of the components perpendicular to the axial direction.

In an alternative embodiment, neither the wave guide cavity **125** nor the magnetic insert stub **132***a* has threads, and the magnetic insert stub **132***a* is press fit into the wave guide cavity **125**. Press fitting may require heating the end of the wave guide **102** with the wave guide cavity **125** to about 500 C and placing the magnetic insert stub **132***a* into liquid nitrogen or vice versa. Such a process results in a strong connection between the two components, but can be a relatively expensive procedure. In another alternative embodiment, the female end of the open-ended magnetic insert **122***a*, i.e., the magnetic insert cavity **136**, has threads around its circumference for coupling with threads located on the tool insert stub **130**. In this way, the tool insert stub **130** can be screwed into the open-ended magnetic insert **122***a* prior to the connection being enhanced with magnetics, i.e., the magnetic coupling system **110***a*.

In yet another alternative embodiment shown in FIG. **2**, a dual-stubbed magnetic insert **122***b* is used. In this embodiment, the dual-stubbed magnetic insert **122***b* has the magnetic insert stub **132***a* as shown in FIGS. **1**A and **1**B. Rather than an opposing female end, however, the dual-stubbed magnetic insert **122***b* has an opposing magnetic insert stub **132***b*. In order to accommodate the opposing magnetic insert stub **132***b*, the tool insert **104** is also modified to have a female end or tool insert cavity **210** as shown in FIG. **2**. The opposing magnetic insert stub **132***b* does not have any threads, and couples with the tool insert **104** by slipping into a tool insert cavity **210**, with tolerances similar to those described in FIG. **1**B. As shown in FIG. **2**, opposing magnetic insert stub **132***b* can be slightly longer than magnetic insert stub **132***a* in order to provide a suitable amount of transverse stability to the tool insert **104**. In one embodiment, the magnetic insert stub **132***a* extends about 0.1 to about 100 cm into the wave guide and the opposing magnetic insert stub **132***b* extends about 0.1 to about 150 cm into the tool insert **104**. In an alternative embodiment, the opposing magnetic insert stub **132***b* is threaded and screws into suitable threads in the wave guide cavity **210**. In another alternative embodiment, the magnetic insert stub **132***a* does not have magnetic insert threads **134**, and is instead press fit into the wave guide cavity **125** as described above.

The magnetic insert(s) used in the magnetic coupling system **110***a* (or **110***b* or **110***c* described below) are essentially "flux catchers" or channels, and can be made from any suitable material which exhibits a net magnetization strong enough to hold the mating parts together during operation. Specifically, the material must have a suitable magnetic permeability, i.e., be able to pass or conduct lines of a magnetic force. In one embodiment, the permeability of the magnetic insert is about 50 to 5,000, up to about 100,000 or more. In one embodiment, the magnetic insert is ferromagnetic. A ferromagnetic material is a substance which has a high magnetic permeability, a definite saturation point, significant residual magnetism and low hysteresis. Ferromagnetic materials are typically characterized as either "hard" or "soft" materials. Permanent (or hard) magnets having a high coercivity of greater than about 100 to about 20,000 oersted (Oe) can be used as the magnetic insert. Temporary (or soft) magnets with a low coercivity of less than about 100 Oe can also be used, depending on the particular application.

In one embodiment, the magnetic insert comprises a soft ferromagnetic material, such as iron, amorphous iron alloys, amorphous cobalt alloys and permalloy. This includes, but is not limited to, iron-aluminum alloys containing about 12 to 16 percent aluminum. This also includes, but is not limited to, various soft ferrites and silicon steels, including nonoriented and grain-oriented steels having varying amounts of silicon from about 0.5 to about five (5) percent. Soft ferromagnetic materials further include, for example, iron-cobalt alloys having up to about 65 percent cobalt. It is known that such alloys have a higher magnetic saturation value than pure iron. In one embodiment, vanadium permendur, which contains about 49% cobalt, 49% iron and about two (2)% vanadium is used.

In another embodiment, the magnetic insert is a hard ferromagnetic material such as carbon steel, bonded rare earth materials, a class of copper-manganese-tin alloys known as "Heusler" alloys, tungsten steel, hard ferrites, neodymium-iron-boron materials and samarium-cobalt materials. This includes, but is not limited to, iron-nickel alloys which can have from about 25 to 60 percent nickel. Alloys containing about 30 percent nickel can also be used and are useful in magnetic circuits when temperature-related changes may occur. Other materials which can be used include certain alloys of cobalt, titanium, aluminum and nickel, commonly known as "alnico." This includes, for example, alnico 2, alnico 5 (Ticonal), alnico 5DG, alnico 6, alnico 9, alcomax II and alcomax m. In an alternative embodiment, barium oxide or strontium oxide magnets, i.e., ceramic magnets, are used. In another alternative embodiment, paramagnetic inserts made from materials such as aluminum, platinum, manganese and chromium, are used.

Referring again to FIG. **1**A, the permanent magnet **120** can be embedded into or secured onto the handpiece **102** in any suitable manner. In one embodiment, an internal plastic or metal clip (not shown) is used to hold the permanent magnet **120** in place. In another embodiment, the permanent magnet **120** is permanently affixed to the handpiece **102** with any type of conventional adhesive. The permanent magnet **120** can be located in a suitable secondary cavity within the handpiece **102**. The permanent magnet **120** can be any suitable shape and size. In the embodiment shown in FIG. **1**A, the permanent magnet **120** is cylindrical, having an external diameter of about one (1) to about five (5) cm (about 0.4 to about two (2) in), a length of about one (1) to about 12 cm (about 0.4 to about 4.7 in) in length, and a thickness of about 0.1 to about ten (10) cm (about 0.4 to about four (4) in).

FIG. **3** is an end view of the magnetic coupling system **110***a* in FIG. **1**A looking toward the magnetic insert cavity **136** (before the tool insert **104** is in place). As shown in FIG. **3**, the cylindrical permanent magnet **120** surrounds the open-ended magnetic insert **122***a* which is located within the handpiece cavity **103** and connected to the wave guide **108** (not shown). The permanent magnet **120** can be made from any suitable hard magnetic material as discussed above. This includes various grades of neodymium iron boron, samarium cobalt, barium oxide, strontium oxide, and so forth. In one embodiment, the permanent magnetic materials described herein are manufactured according to current commercial standards, such as the standards and specifications established by The Magnetic Materials Producers Association (MMPA) in the "Standard Specifications for Permanent Magnet Materials," MMPA Standard No 0100-96, as reprinted on pages 188–788 of the "Permanent Magnet Design and Application Handbook," 2d edition, by L. Moskowitz, or any comparable or updated standards for permanent magnetic materials. In one embodiment, the permanent magnet **120** is shipped in a demagnetized state from the manufacturer, and is magnetized again after placement in the final magnetic circuit.

The general principles of magnet manufacturing as well as magnetism and permanent magnet design are well known in the art and are not discussed in detail herein. See, for example, Chapters 5–14 of Moskowitz, supra, which are hereby incorporated by reference in their entirety. Many factors can affect the performance of a magnet, including, but not limited to, magnet material, size, shape, and location of the magnet in the magnetic circuit, level of magnetization, location of magnetic poles, magnetization before or after placement in a final circuit, material from which other components are made, shape of the other components, temperature, radiation, shock, demagnetizing fields, physical handling during assembly, time, the material of the part on which the magnet acts, the size, shape and location of the part on which the magnet acts, and so forth. (See p. 40 of Moskowitz, supra).

In the embodiment shown in FIG. **1**A, the permanent magnet **120** is placed longitudinally in the cavity **103** such that the largest surface area of the permanent magnet **120** is pointed directly at the open-ended magnetic insert **122***a*. With this configuration, it is possible to use a permanent magnet **120** which has been manufactured to have any one of a number of different polarizations. Polarization is the primary direction toward which lines of magnetic flux vectors are pointing. In one embodiment, magnetic coupling is achieved by radial (90 degrees) polarization of the permanent magnet **120** relative to the centerline of the mating parts (FIGS. **4** and **5**A). In another embodiment, magnetic coupling is achieved using axial (0 degrees) polarization of the permanent magnet **120** (FIG. **5**B). In yet another embodiment, magnetic coupling is achieved using an intermediate angle (0–90 degrees) of polarization of the permanent magnet **120** (FIG. **5**C). Use of such "off-axis" polarization (relative to the axial axis) may be advantageous in creating a larger magnetic force as compared with polarization along the axis. Therefore, the axial alignment of the permanent magnet **120** with the open-ended magnetic insert **122***a* (or double-stubbed magnetic insert **122***b*) can vary depending on the particular application and the amount of magnetic attraction desired.

FIG. **4** is a cross-sectional partial view of a dental tool having a magnetic coupling system **110***a* with a permanent magnet **120** which is radially polarized. In this embodiment, two magnetic inserts **122***a* and **122***b* are used. As noted above, two magnetic inserts are typically used when both the wave guide **108** and the tool insert **104** are non-magnetic. The open-ended magnetic insert **122***a* which couples with the wave guide **108** has been described above in FIGS. **1**A and **1**B. The dual-stubbed magnetic insert **122***b* which couples with the tool insert **104** is similar in design to the dual-stubbed magnetic insert **122***b* shown in FIG. **2**. In this embodiment, however, the magnetic insert stub **132***a* is not threaded and the opposing magnetic insert stub **132***b* is threaded. The poles of the permanent magnet **120** are marked on the drawing by the letters "N" and "S," and are oriented such that all vectors or flux lines **410** point radially inwardly towards a centerline **412** as shown, passing through the open-ended magnetic insert **122***a* and the dual-stubbed magnetic insert **122***b*.

Similarly, FIG. **5**A shows a perspective view of the magnetic coupling system **110***a* in which the permanent magnet **120** is radially magnetized. As with FIG. **4**, flux lines **410** exit the permanent magnet **120** radially towards the centerline **412** at a 90 degree angle (θ) **514***a* relative to the longitudinal axis of the permanent magnet **120**. Again, the flux lines **410** are directed radially inward before turning back across an air gap, which is generally defined as any nonmagnetic discontinuity in a magnetic circuit. (Although the poles and orientation of the dual-stubbed magnetic insert **122***b* are not noted on these drawings, it can be assumed that the dual-stubbed magnetic insert **122***b* is aligned such that it exerts a magnetic attraction at each end for each of the mating parts being combined).

FIG. **5**B shows an alternative embodiment in which the magnetic coupling system **110***a* utilizes a permanent magnet **120** which is axially polarized. In this embodiment, the poles (N and S) of the permanent magnet **120** are located at opposite ends as shown, such that polarization is parallel to the axial axis of the dual-stubbed magnetic insert **122***b*. Specifically, flux lines **510** exit one end of the permanent magnet **120**, curving back along the length of the permanent magnet **120**, such that angle (θ) **514***b* is zero (0) degrees. The flux lines **510** are attracted toward the dual-stubbed magnetic insert **122***b*, causing them to curve back into an opposing end of the permanent magnet **120** toward the dual-stubbed magnetic insert **122***b*, as shown.

FIG. **5**C shows another alternative embodiment in which the magnetic coupling system **110***a* utilizes a permanent magnet **120** which has an intermediate angle of polarization. In this embodiment, the poles (N and S) are located along the length of the permanent magnet **120** as shown. Flux lines **520** exit the permanent magnet **120** radially inward at an acute angle (θ) **514***c* relative to the longitudinal axis of the permanent magnet **120**. The flux lines **520** then pass through the dual-stubbed magnetic insert **122***b* and return to the permanent magnet **120** as shown, such that the entire permanent magnet **120** is magnetized radially inwardly. In one embodiment, the angle (θ) **514***c* is any acute angle greater than zero (0) degrees. In another embodiment, the angle (θ) **514***c* is between about 30 and 60 degrees.

In one embodiment, soft magnetic materials are used to shape and intensify the magnetic flux density or magnetic field strength. In a particular embodiment, the magnetic flux density is doubled when magnetic material is placed on the outside of the permanent magnet **120** and has flux vectors pointed radially inward.

In another alternative embodiment (not shown), two or more permanent magnets **120** are used. In this embodiment, each permanent magnet **120** does not necessarily surround the magnetic insert (**122***a* or **122***b*), but can be placed at suitable intervals around the interior circumference of the handpiece **102**, so that the magnetic insert is effectively surrounded by a group of permanent magnets **120**, each of which can have a solid core. In one embodiment, the permanent magnets **120** are arranged to reduce leaking and fringing flux. An overview of permanent magnet structures, including a discussion of leakage flux and fringing flux is provided in U.S. Pat. No. 5,886,609 to Stelter, which is hereby incorporated by reference in its entirety.

Referring again to FIG. **1**A, the motor **106** can be any suitable type of motor having a drive rod capable of generating sufficient power for a particular application. In one embodiment, the drive rod is made from a smart or active material, such as a magnetostrictive, piezoelectric or piezoceramic material. A magnetostrictive material is known to tolerate high mechanical stress and have a relatively high energy density. In a particular embodiment, a drive rod made from a magnetostrictive material known as TERFENOL-D is used. TERFENOL-D is manufactured by the Assignee of this application, ETREMA Products, Inc. of Ames, Iowa. In one exemplary embodiment, a "High Power Ultrasonic Motor" as described in U.S. or PCT Applications, supra, is used. In a specific embodiment, a six (6) kW motor **106** having boron nitride parts is used.

In another embodiment, the high power ultrasonic motor as described in U.S. and PCT Applications, supra, may be modified in any suitable way as needed for a particular application. For example, a smaller or larger motor can be used. Alternatively, the power supply may be of the impulse or continuous type. In one embodiment, the motor **106** is cylindrical in shape and is less than about 7.6 cm (about three (3) in) in diameter and less than about 10.2 cm (about four (4) in) in length. In another embodiment, the motor **106** is at least about 1.3 cm (0.5 in) in diameter and about 2.5 cm (one (1) in) in length.

In an alternative embodiment, the motor **106** is smaller than the motors described in U.S. and PCT Applications, supra, because there are no separate cooling fixtures. The elimination of cooling fixtures is possible in applications where no additional cooling is needed, such as in the dental field, wherein fluid is actively passed through the motor **106** in order to provide irrigation during dental procedures. In such applications, a hole can be bored through the center of the motor **106**, allowing the water or other cooling fluid to pass through the center bolt. Preload is provided by the bolt, rather than a Belleville spring, as in U.S. and PCT Applications, supra. Necessary adjustments can be made to the bolt to reduce its stiffness, so that it has the necessary softness similar to a Belleville spring. Cooling is also typically not needed in small motors consuming less than about ten (1) to 20 watts of power.

The motor **106** used with the magnetic coupling system **110***a* shown in FIG. **1**A can operate at any suitable frequency. In one embodiment, the operating frequency is ultrasonic, such as between about 18 kHz and 100 kHz. In another embodiment, the motor **106** operates between about 25 kHz and about 40 kHz, such as with a dental tool and other similar devices. In yet another embodiment, frequencies below about 18 kHz are used. Frequencies below 25 kHz are more likely used for applications such as impact hammers, compaction equipment, and so forth.

Any suitable amount of power can be transmitted from the electronics **114** to the motor **106**. In one embodiment, less than about ten (10) watts of power is transferred. In an alternative embodiment, about ten (10) to 20 watts or more of power is transferred from the electronics **114** to the motor **106**. Further, any suitable amount of power can be output from the motor **106**. In one embodiment, about 30 to 70% or more of the power input to the motor **106** is output by the motor **106** through the magnetic coupling system **110***a*. In another embodiment, about 40 to 50% is output. In a specific embodiment, about 13 watts of power is input from the electronics **114** to the motor **106** and about 5.8 to six (6) watts, i.e., about 46%, is output by the motor **106** through the magnetic coupling system **110***a*.

The magnetic coupling system **110***a* can transfer energy from the motor **106** to the tip **128** at any suitable efficiency. In one embodiment, the coupling efficiency of the magnetic coupling system **110***a* is about 30 to 50% up to about 60% or 70% or more, up to 100% of the power generated by the motor **106**. The efficiency of the magnetic coupling system **110***a* can also be expressed in terms of the vibrational output or amplitude. For example, in one embodiment, an amplitude of about one (1) to 100 μm is generated in the wave guide **108** by the motor **106**, and an amplitude of about 0.9 to 100 μm, i.e., about 90 to 100%, is output at the tip **128**.

The size and shape of the tool insert **104** and the wave guide **108** can be varied depending on the frequency used and the type of function or work performed by the tool insert **104**. As noted above, the wave guide **108** can be any length in relation to the tool insert **104**, and in one embodiment, is about one-half the length of the tool insert **104**. In such an embodiment, the wave guide **108** has about ¼ the wavelength of sound propagation in the material for any given frequency as compared with the tool insert **104**. In one embodiment, a motor **106** having a frequency output of about 20 kHz is used together with a tool insert **104** having a diameter of about two (2) to three (3) cm (about 0.8 to 1.2 in) and a length of about ten (10) to 12 cm (about four (4) to 4.7 in). A wave guide **108** which is one-half the length of the tool insert, i.e., about five (5) to six (6) cm (about two (2) to 2.4 in), can be used, if desired. The amplitude of the displacement at the tip **128** can also vary depending on the application. In one embodiment, the displacement amplitude is about one (1) micron to about 300 microns. In another embodiment, the displacement amplitude is about 100 microns peak-to-peak.

Power can be provided from any suitable source of energy, including, but not limited to, a generator, conventional batteries, a solar energy system having solar panels and storage batteries, or a normal power grid system. The magnetic coupling system **110***a* can operate on either alternating current (AC) or direct current (DC), and the voltage can be any suitable voltage such as 12 volts or 120 volts, depending on the source of the power. In one embodiment, a battery pack system is used. In this embodiment, the battery pack supplies DC power to a conversion circuit. The conversion circuit converts the DC power to any desired frequency range, such as from about one (1) Hz to 50 kHz. A controller can also be used to adjust the amplitude and frequency for a particular application. In an alternative embodiment, an AC line source of any origin can be used. The AC source is converted to any desired frequency range, such as from about one (1) Hz to 50 kHz. The magnitude and frequency of the oscillations can also be controlled for a particular application.

In the embodiment shown in FIG. **1**A, a source of air power is used to activate the motor **106**. Specifically, when the power adjustment switch **118** is activated, a supply of air (not shown) is drawn into the turbine **111** through the air connector **116**. The rotating motion of the turbine components is transmitted through the turbine-generator connector **109** to the generator **112**. The generator **112** converts this mechanical energy into electrical energy and sends the appropriate signal through the generator-electronics connector **113** to the drive electronics **114**, which in turn activates the motor **106** via the electronics-motor connector **115**. Conventional connections, such as tubing and wiring, which are well known in the art are used for the various connectors (**109**, **113**, **115** and **116**) described herein. The power adjustment switch **118** can be a simple on/off switch. In an alternative embodiment, the power switch **118** is a dial switch. In this embodiment, a range of power output is possible, so that the output (such as the amplitude of vibration) can be set at the appropriate level for a particular application and so that the power level can be adjusted as needed during a particular application.

In operation, the user places the tool insert **104** into the magnetic insert (**122***a* or **122***b*), which is in turn threaded to the wave guide **108**. Alternatively, the tool insert **104** can be attached directly to the wave guide **108** if both components are sufficiently magnetic. In the embodiment shown in FIG. **1**A, the open-ended magnetic insert **122***a* has already been threaded into the wave guide **108** as described. When the power adjustment switch **118** is turned on, power is provided to the motor **106** as described above. Once the motor **106** is activated, energy from the motor **106** is transmitted to the magnetic coupling system **110***a* to create a magnetic field around the permanent magnet **120**. The magnetic field provided by the permanent magnet **120** can clamp the two mating parts (wave guide **108** and tool insert **104**) together with up to about 17.8 Newtons (N) (about four (4) lbf) or more of force. The energy from the motor **106** is further transferred across the magnetic coupling system **110***a* from the wave guide **108** to the tool insert **104**. In the embodiment shown in FIG. **1**A, ultrasonic energy in the form of vibrations **124** are transferred across the magnetic coupling system **110***a*. At this point, the user can then use the device to perform the desired function, such as cleaning calculus from teeth, and so forth. The tool insert **104** is removable by firmly pulling the tool insert **104** away from the wave guide **108**, preferably after the power is turned off.

FIG. **6** shows a cross-sectional view of one embodiment of the present invention comprising an alternative magnetic coupling system **110***b*. The handpiece **102** contains the motor **106**, wave guide **108**, alternative magnetic coupling system **110***b*, turbine **111**, generator **112** and electronics **114** as described above. The alternative magnetic coupling system **110***b* uses an electromagnet **620** rather than the permanent magnet **120** used in the magnetic coupling system **110***a*. The alternative magnetic coupling system **110***b* shown in FIG. **6** shows two open-ended magnetic inserts **122***a*. The use of two open-ended magnetic inserts **122***a* is for exemplary purposes only, as it is also possible to use only one open-ended magnetic insert **122***a* (or one dual-stubbed magnetic insert **122***b*), or any other type and number of magnetic inserts, depending on the particular application and type of materials, as discussed above. Specifically, two magnetic inserts can be used when neither of the mating parts, i.e., the wave guide **108** nor the tool insert **104**, are magnetic or are otherwise weakly magnetic, such as paramagnetic materials or possibly diamagnetic materials. Otherwise, if one of the mating parts is sufficiently magnetic, only one magnetic insert needs to be used as in FIG. 1A.

The electromagnet **620** in the alternative magnetic coupling system **110***b* comprises an internal magnetic bobbin **622**, a coil wire **624** having lead wires **626**, and an external magnetic bobbin **628**. (For clarity, the components of the alternative magnetic coupling system **110***b* are shown in a partially expanded view so that they appear separated, although in use, the wave guide, the open-ended magnetic inserts **122***a* and the tool insert **104** are all in direct contact as in previously described embodiments). The coil wire **624** is wrapped around the internal magnetic bobbin **622** such that the lead wires **626** extend past the end of the internal magnetic bobbin **622** as shown. In the embodiment shown in FIG. **6**, there are two windings of the coil wire **624** and the two lead wires **626** extend out from the same end of the internal magnetic bobbin **822**. In an alternative embodiment, any number of windings can be used and the lead wires **626** can extend out from any portion of the internal magnetic bobbin **622**. The external magnetic bobbin **628** provides a "covering" for the coil wire **624** and functions to increase the magnetic flux density. In an alternative embodiment, there is no external magnetic bobbin **628**.

In the embodiment shown in FIG. **6**, there is one electromagnet **620** surrounding the open-ended magnetic inserts **122***a*. The electromagnet **620** is lodged inside the handpiece **102** in any suitable manner, such as the various ways in which the permanent magnet **120** in FIG. **1A** can be embedded in the handpiece **102**.

The internal and external magnetic bobbins, **622** and **628**, respectively, can be any suitable size and can be made from any suitable magnetic material as is known in the art for electromagnets, including all of the magnetic materials described herein. In one embodiment, the internal and external magnetic bobbins, **622** and **628**, respectively, are about one (1) to ten (10) cm (about 0.4 to four (4) in) in length and about one (1) to ten (10) cm (about 0.4 to four (4) in) in diameter.

The wire coil **624** can be made from any suitable electrically conductive material as is known in the art, including, but not limited to copper, silver and aluminum. The size of the wire coil **624** depends on the particular application. Generally, for hand held tools, a smaller size may be desirable, so that the wire is not too large or heavy. In one embodiment, the wire coil **624** is about 16 American Wire Gauge (AWG) to about 36 AWG. In another embodiment, the wire coil **624** is about 12–15 AWG or less.

As with the open-ended magnetic insert **122***a* in FIG. **1A** that couples with the wave guide **108**, the open-ended magnetic insert **122***a* in FIG. **6** that couples with the wave guide **108** can have suitable threads **134** on its magnetic insert stub **132***a* so that it can be screwed into the wave guide **108**. Similarly, the magnetic insert cavity **136** associated with this open-ended magnetic insert **122***a* has no threads, nor does the magnetic insert stub **132***a* of the adjacent open-ended magnetic insert **122***a*, because these two components are not screwed together, but instead are inserted together. In this way, the magnetic coupling system **110***b* (or **110***a*) is used to enhance a raw connection with magnetics, i.e., the magnetic coupling system **110***b*, rather than merely being used to enhance a threaded connection. This adjacent open-ended magnetic insert **122***a* shown in FIG. **6** is threaded to the tool insert **104** via threads on the tool insert stub **130** and threads surrounding the circumference of the magnetic insert cavity **136**. In an alternative embodiment, the two open-ended magnetic inserts **122***a* are threaded together, with the connection being enhanced by magnetics. Other alternative embodiments include press fitting one of the open-ended magnetic inserts **122***a* into the wave guide cavity **125** and/or press fitting one open-ended magnetic insert **122***a* into an adjacent magnetic insert **122***a*. In another alternative embodiment, at least one of the magnetic inserts is dual-stubbed as shown in FIG. **2**. In yet another alternative embodiment, one of the magnetic inserts is essentially dual-stubbed, but has only a small protrusion or extension on one end which fits or slips into a corresponding cavity of the adjacent magnetic insert without threads.

The open-ended magnetic inserts **122***a* in FIG. **6** are arranged to exert a magnetic attraction force for one another. It is known that magnetic field strength is directly proportional to the size of the current. In this way, when current is applied to the lead wires **626**, a strong magnetic field is created between the open-ended magnetic inserts **122***a*. The current also causes a strong magnetic field to be created around the electromagnet **620**, which surrounds the open-ended magnetic inserts **122***a*. This causes the two mating parts (wave guide **108** and tool insert **104**) to be magnetically attracted together. Any suitable current can be used. In one embodiment, the current is about 50 milliamps (mA) to about ten (10) amps (A), depending on the size of the wire.

FIG. **7** shows a perspective view of the electromagnet **620** without an external magnetic bobbin **628**, surrounding a dual-stubbed magnetic insert **122***b*. Since the wire coil **624** can only produce axial magnetic flux, the electromagnet **620** can only be magnetized in the axial direction, similar to the permanent magnet **120** shown in FIG. **5B**. This is indicated by the flux vectors **710** as shown in FIG. **7**. Again, although the poles and orientation of the dual-stubbed magnetic insert **122***b* is not noted on FIG. **7** it can be assumed that the dual-stubbed magnetic insert **122***b* is aligned such that it exerts a magnetic attraction at each end for each of the mating parts being combined.

In operation, when there is no current being applied to the wire coil **624**, a user can place the tool insert **104**, such as a dental scaler, onto the wave guide **108**. Once the tool insert **104** is in place, the wire coil **624** can be energized by moving the power adjustment switch **118** to the "on" position as described above. The magnetic field created by the wire coil **624** induces a strong magnetic field between the magnetic inserts as noted above. In one embodiment, the magnetic field can produce as much as about 22.3 N (five (5) lbf) or more of attraction force securing the components to each other with small amounts of power. The attraction force can be determined according to mathematical relationships well known in the art and discussed in Moskowitz, supra. The power consumption required to produce this force will vary depending on several factors known in the art, including the amount of air in the magnetic circuit. In one embodiment, the power required is about five (5) to 15 watts or more. In an alternative embodiment, the power required is less than about three (3) watts of power. In another alternative embodiment, the diameter of the internal magnetic bobbin **622** is about five (5) to about 7.6 cm (about two (2) to about three (3) in). In this embodiment, the magnetic field can produce as much as about 3,234 N (725 lbf) or more of attraction force with an input power of up to about 500 watts or more.

The connector scheme shown in FIG. **8** uses a passive magnetic coupling system **110***c* to couple the wave guide **108** to the tool insert **104**. (Again, for clarity, the components of the passive magnetic coupling system **110***c* are shown in a partially expanded view so that they appear separated, although in use, the wave guide, the open-ended magnetic inserts **122***a* and the tool insert **104** are all in direct contact as in previously described embodiments). The handpiece **102** shown in FIG. **8** contains the motor **106**, wave guide **108**, turbine **111**, generator **112** and electronics **114** as described above. In the embodiment shown in FIG. **8**, however, the handpiece **102** contains a passive magnetic coupling system **110***c* which comprises two open-ended magnetic inserts **122***a* and a high power magnet **810**, all of which are magnetized prior to being placed in the magnetic circuit. Firm connection occurs when the tool insert **104** is inserted over the high power permanent magnet **810**. The magnetic field can clamp the two mating parts (wave guide **108** and tool insert **104**) together with up to about 17.8 N (about four (4) lbf) or more of force. The tool insert is modified as in FIG. **2** to have a tool insert cavity **210**. Additionally, in the embodiment shown in FIG. **8**, the tool insert cavity **210** has threads **812**. The tool insert **104** is removable by firmly pulling the tool insert **104** away from the wave guide **108**. In an alternative embodiment, there are no threads on the magnetic insert stubs **134***a*, and the components are inserted together, with the raw connection being enhanced by magnetics, i.e., the magnetic coupling system **110***c*, as described above.

The high power magnet **810** is positioned in a cavity created by the two open-ended magnetic inserts **122***a*, each having a cavity **136**, as described above in FIGS. **1**A and **1**B and shown in FIG. **8**. In one embodiment, one or both of the cavities **136** are modified to be larger than the cavity **136** in the open-ended magnetic inserts **122***a* described above. Specifically, the cavities **136** can be of any suitable size and shape, and are located opposite the magnetic insert stubs **132**, i.e., opposite the ends which connect with the two mating parts. Placing two cavities **136** together in this manner provides the space for the high power magnet **810**. The high power magnet **810** is a permanent magnet having remanent magnetic field values greater than about 2500 gauss.

FIG. **9** shows an exploded view of the passive magnetic coupling system **110***c* comprising the high power magnet **810** between the two open-ended magnetic inserts **122***a*. The poles of the high power magnet **810** are indicated by "N" and "S." The high power magnet **810** exerts an attraction force for both of the open-ended magnetic inserts **122***a*. Further, it can be assumed in this embodiment that the open-ended magnetic inserts **122***a* are axially aligned and that each exert an attraction force for the component to which it attaches. Flux lines **902** exit the high power magnet **810** as shown, such that the flux is parallel to the axis of the high power magnet **810**, and is not directed radially inward. The high power magnet **810** can be any suitable shape, such as square, rectangular, barrel or elliptical. In one embodiment the high power magnet **810** is circular. In another embodiment a Cast Alnico **57** magnet having a residual induction (Br) of 13,500 gauss made by Crucible Magnetics in Elizabethtown, Ky. is used.

The present invention is also directed to a method of releasably coupling a tool insert, such as a dental scaler insert, by using a magnetic coupling interface. The method includes the use of a magnetic coupling system as described above, and includes the steps of inserting a tool insert onto a magnetic insert and causing the magnetic insert to indirectly or directly contact a cavity in a wave guide. In an alternative embodiment, there is no wave guide, and contact is made directly or indirectly with a motor, such as an ultrasonic motor. The method further includes activating a permanent magnet or electromagnet located proximate to the magnetic insert in order to provide a magnetic coupling between the wave guide and tool insert.

In addition to providing a method for releasably connecting two mating parts, the magnetic coupling systems of the present invention also transmit energy from one component to another. In one embodiment, ultrasonic energy is transferred to the tool insert **104**, thus causing the tip **128** to vibrate as discussed above in relation to FIGS. **1**A, **6** and **8**. Any suitable amount of magnetic force or pressure can be used to hold the mating parts together, depending on the application. In one embodiment, the stress at the magnetic attachment plane is about 0.69 MPa (about 100 psi). This corresponds to a force of about 22.3 N (five (5) lbf) such that the magnetic attraction force at the magnetic attachment plane is greater than 22.3 N (five (5) lbf), such as about 27.7 N (about six (6) lbf). As a result, the components of the magnetic coupling system stay in contact, thus allowing for efficient transmission of vibration through coupling. In an alternative embodiment, the magnetic assembly holds two components together with a force of about 10 N (about 2.2 lbf). In another alternative embodiment, the components are held together with a force of about 600 N (about 135 lbf).

FIG. **10** is a system drawing showing the components through which energy is transferred. This includes the air supply **109**, turbine **111**, generator **112**, electronics **114**, motor **106**, wave guide **108**, magnetic coupling system **110**(*a, b* or *c*) and tool insert **104** discussed herein. Any conventional turbine **111** can be used in this invention, such as a conventional air turbine. The turbine **111** can have performance characteristics suitable for the particular application. It is known that turbine shaft output is dependent on turbine efficiency. In one embodiment, the input air supply power is about 60 to about 90 watts. In another embodiment, the air turbine **111** is any type of conventional turbine well known in the dental field having a power output of about ten (10) to about 50 watts. In a particular embodiment, an RDH vane motor made by Midwest Dental, Inc., in Des Plaines, Ill., is used. The air supply **509** connected to the turbine **111** can be at any suitable pressure, such as about 0.28 to 0.345 MPa (about 40 to 50 psi).

Any conventional generator **112** can be used, such as a DC generator. The generator **112** preferably has performance characteristics suitable for a particular application. Both the turbine **111** and generator **112** are designed to be capable of producing sufficient power output for the particular motor **106** being used.

The electronics **114** can comprise conventional drive electronics known in the art. The electronics **114** are used to power the motor **106** using the DC voltage supplied by the turbine **111** and generator **112**. In one embodiment about 25 to about 40 kHz of DC power is provided. A potentiometer can also be used to regulate or adjust the power which is output from the generator **112** to the electronics **114**. In one embodiment, the system utilizes open loop control with variable gain used to regulate the electronics **114**.

Regarding testing and analysis of the magnetic coupling system, modal analysis is a well-known method for providing information on the manner in which objects vibrate. By performing modal analysis, it is possible to determine a preferred coupling system location which will require a minimum amount of pressure to hold the mating parts together. If the magnetic coupling system does not have adequate attraction, the existing stress or pressure of the vibration will cause the tool insert to detach from the wave guide. Modal analysis involves determination of the relationship between the velocity and pressure of the system. An "antinode" is a location of zero pressure and maximum velocity. A "node" is a location of maximum pressure or stress and zero velocity. In actual applications, the antinode and node may not be precisely defined, such that there may exist a small amount of pressure at the antinode and some velocity at the node.

In one embodiment, the stress state near the anti-node, or point of coupling, is sufficiently low so that magnetic coupling is feasible. Additional modal analysis will be used to optimize the system and ensure that adequate attraction is provided.

Testing will be performed using a hand held dental scaler to determine performance characteristics of the various system components. Turbine, generator, electronics and motor designs will be integrated together, and the system will be tested to determine various performance characteristics such as resonant frequency, ultrasonic motor transfer function, generator power, ultrasonic motor power input, and so forth. Magnetic, mechanical and dynamic analysis will be performed to design a tip for optimum elastic wave energy transmission.

Air turbine performance characteristics of various Midwest Dental air turbines and turbines produced by other manufacturers will be reviewed. In order to complete this testing, power curves showing torque vs. rpm will be used for each particular turbine.

Various off-the-shelf generators will be tested. A DC motor may also be used to simulate the operation of a generator by running it backwards. The best performing generators and turbines will be tested together to determine output power capability. The requisite air supply and tubing for this testing will be supplied by Dentsply of York, Pa. Compatibility of the turbine/generator power output capability and estimated power requirements of a 25 kHz ultrasonic motor (and likely other ultrasonic motors), will be evaluated.

Drive electronics will be designed to power a selected ultrasonic motor using the DC voltage supplied by the turbine/generator. Electronics design schematics will be based on previously known battery-operated systems.

A suitable ultrasonic motor will be developed. This may be a 25 kHz motor, a 30 kHz motor, or a motor having some other suitable frequency. For a 25 kHz motor, such design and development will begin with a 25 kHz tip design and dimensional information supplied by the maker of the tool insert to be used. For the 25 kHz motor, it is likely a 25 kHz Dentsply dental tip will be tested. In this way the motor will be designed as a system including tip dynamic effects. It is possible that other ultrasonic motors designed for having different tip dynamic effects will be developed and tested as well. Magnetic, mechanical, electrical as well as modal analyses will be performed to maximize device efficiency and ensure compatibility with the selected power generator.

CONCLUSION

Magnetic coupling of components, whether at ultrasonic or sonic frequencies, can be used in a variety of applications. Some areas of use include, but are not limited to, the coupling of components in high power ultrasonic sonochemical applications, sonic and ultrasonic knife blades for the enhancement of cutting, coupling of acoustic elements between motor and loud speakers or warning systems, the connection of ultrasonic surgical motors to surgery implements, and so forth.

The magnetic coupling system gives the user the ability to quickly remove and attach implements. The method is cost effective because it is no longer necessary to discard an entire motor when a tool insert needs replacement. Furthermore, the method is relatively simple and inherently gives devices longer reliability than devices coupled using conventional methods, because problems such as galling and thread wear are not present. Those skilled in the art will recognize that the magnetic interface described herein can be used in any suitable system which comprises the necessary mechanical and electrical components, as well as a suitable type of system controller, if applicable.

Although specific embodiments have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that any arrangement which is calculated to achieve the same purpose may be substituted for the specific embodiment shown. This application is intended to cover any adaptations or variations of the present invention. Therefore, it is manifestly intended that this invention be limited only by the claims and the equivalents thereof.

What is claimed is:

1. A magnetic coupling system comprising a magnetic assembly having one or more permanent magnets or an electromagnet located proximate to coupling ends of a base structure and tool insert, the magnetic assembly designed to removably combine the base structure and tool insert, wherein the base structure has a transducer which provides vibrational motion that can be transmitted through the magnetic assembly directly to the tool insert.

2. The system as recited in claim **1** wherein the vibrational motion in the base structure is transformed to elliptical or flexural motion in the tool insert.

3. The system as recited in claim **1** wherein the magnetic assembly can hold the base structure and tool insert together with a force of about ten (10) to about 600 Newtons.

4. The system as recited in claim **1** wherein the transducer is an ultrasonic motor, further wherein ultrasonic energy is passed from a wave guide in direct contact with the motor to the tool insert.

5. The system as recited in claim **4** wherein the tool insert is an ultrasonic dental scaling tool.

6. The system as recited in claim **5** wherein the wave guide is made from titanium and the tool insert is made from steel.

7. The system as recited in claim **4** wherein the ultrasonic motor operates at frequencies between about 18 kHz and 40 kHz.

8. The system as recited in claim **1** wherein the transducer is a sonic motor operating at frequencies less than about 18 kHz, further wherein sonic energy is passed from a wave guide in direct contact with the motor to a tool insert.

9. The system as recited in claim 1 wherein power means provide power to the transducer through electronics connected to the transducer.

10. The system as recited in claim 1 wherein the magnetic assembly further comprises one or more magnetic inserts located between the base structure and tool insert, further wherein one or both of the base structure and tool insert are non-magnetic, paramagnetic or diamagnetic.

11. The system as recited in claim 10 wherein the one or more permanent magnets surround the one or more magnetic inserts.

12. The system as recited in claim 11 wherein the one or more permanent magnets are radially polarized, axially polarized, or polarized at an intermediate angle.

13. The system as recited in claim 10 wherein the permanent magnet is placed between two magnetic inserts.

14. The system as recited in claim 10 wherein the electromagnet surrounds the one or more magnetic inserts.

15. The system as recited in claim 10 wherein the one or more magnetic inserts are made from soft or hard ferromagnetic material.

16. The system as recited in claim 15 wherein the ferromagnetic material is selected from the group consisting of iron, steel, nickel, cobalt, alnico, permalloy, barium oxide and strontium oxide.

17. The apparatus as recited in claim 10 wherein the permanent magnet surrounds the one or more magnetic inserts and is radially polarized, axially polarized or polarized at an intermediate angle.

18. The system as recited in claim 11 wherein the one or more magnetic inserts are open-ended, dual-stubbed or a combination thereof.

19. The system as recited in claim 18 wherein at least one of the one or more magnetic inserts is threaded.

20. An apparatus comprising a passive magnetic coupling system having an ultrasonic transducer adapted to couple with a tool insert, the transducer having a permanent magnet with a remanent magnetic field value greater than about 2500 gauss, the permanent magnet located between two magnetic inserts and designed to magnetically attract the transducer and tool insert together, wherein the permanent magnet and magnetic inserts are magnetized prior to placement in a magnetic circuit, further wherein vibrational energy is transferred from the transducer to the tool insert.

21. The apparatus as recited in claim 20 wherein the magnetic inserts are open-ended.

22. The apparatus as recited in claim 20 wherein the transducer is an ultrasonic motor operating at frequencies between about 18 kHz and 40 kHz, further wherein a wave guide is located between the transducer and the tool insert.

23. The apparatus as recited in claim 22 wherein the wave guide is made from a nonmagnetic material and the one or magnetic inserts are made from iron, steel, nickel, cobalt, alnico, permalloy, barium oxide or strontium oxide.

24. A method for removably coupling a base structure and tool insert together, comprising:

connecting the base structure and tool insert together;

applying a magnetic field to the base structure and tool insert by activating a transducer located in the base structure using power from a power source, the magnetic field produced with a magnetic assembly comprising one or more permanent magnets or an electromagnet located proximate to coupling ends of the base structure and tool insert; and

transferring vibrational energy from the transducer across the magnetic assembly directly to the tool insert.

25. The method as recited in claim 24 wherein the magnetic assembly holds the base structure and tool insert together with a force of about ten (10) to about 600 Newtons.

26. The method as recited in claim 24 wherein the transducer is an ultrasonic motor, further wherein ultrasonic energy is passed from a wave guide in direct contact with the motor to the tool insert.

27. The method as recited in claim 26 further comprising transforming vibrational motion in the base structure to elliptical or flexural motion in the tool insert.

28. The method as recited in claim 27 wherein the tool insert is an ultrasonic dental scaling tool.

29. The method as recited in claim 28 wherein the ultrasonic motor operates at frequencies between about 18 kHz and 40 kHz.

30. The method as recited in claim 24 wherein the transducer is a sonic motor operating at frequencies less than about 18 kHz, further wherein sonic energy is passed from a wave guide in direct contact with the motor to the tool insert.

31. The method as recited in claim 24 wherein the one or more permanent magnets are placed between two magnetic inserts and have remanent magnetic field values greater than about 2500 gauss.

32. The method as recited in claim 24 wherein the electromagnet surrounds the one or more magnetic inserts.

33. The method as recited in claim 24 wherein the one or more permanent magnets surround the coupling ends of the base structure and tool insert.

34. The method as recited in claim 24 wherein one or both of the base structure and tool insert are non-magnetic, further wherein the magnetic assembly also comprises one or more magnetic inserts located between the two components.

35. The method as recited in claim 34 wherein the permanent magnet surrounds the one or more magnetic inserts.

36. The method as recited in claim 35 wherein the permanent magnet is radially polarized, axially polarized or polarized at an intermediate angle.

37. The method as recited in claim 36 wherein the one or more magnetic inserts are made from soft or hard ferromagnetic material.

38. The method as recited in claim 37 wherein the ferromagnetic material is selected from the group consisting of iron, steel, nickel, cobalt, alnico, permalloy, barium oxide and strontium oxide.

39. The method as recited in claim 37 wherein the transducer is an ultrasonic motor, further wherein ultrasonic energy is passed from a wave guide in direct contact with the motor to the tool insert.

40. The method as recited in claim 39 wherein the tool insert is an ultrasonic dental scaling tool.

41. The method as recited in claim 40 wherein the ultrasonic motor operates at frequencies between about 18 kHz and 40 kHz.

42. An apparatus for coupling two components comprising:

means for applying a magnetic field to the two components, wherein the two components are a wave guide and a tool insert;

means for coupling the wave guide and tool insert with the magnetic field; and

means for transferring sound waves directly from the waveguide to the tool insert, wherein the sound waves cause the tool insert to vibrate.

43. The apparatus as recited in claim 42 wherein the means for applying the magnetic field is a motor having a drive rod made from a material selected from the group consisting of magnetostrictive, piezoelectric and piezoceramic materials.

44. The apparatus as recited in claim **43** wherein the magnetostrictive material is Terfenol or Terfenol-D.

45. The apparatus as recited in claim **43** wherein the motor has a frequency output greater than about 18 kHz and a power output of about 5.8 to six (6) watts.

46. The apparatus as recited in claim **45** wherein the motor has no separate cooling fixtures.

47. The apparatus as recited in claim **46** wherein the means for coupling and the means for transferring sound waves is a magnetic coupling system, further wherein torque is not transmitted by the magnetic coupling system to the tool insert.

48. The apparatus as recited in claim **47** wherein the magnetic coupling system is one or more permanent magnets or an electromagnet.

49. The apparatus as recited in claim **48** wherein one or both of the two components are non-magnetic, paramagnetic or diamagnetic, further wherein one or more magnetic inserts are used between the two components.

50. A magnetic assembly having one or more permanent magnets or an electromagnet located proximate to coupling ends of a base structure and a tool insert, the magnetic assembly designed to removably combine the base structure and tool insert, wherein the base structure has an ultrasonic motor capable of operating at frequencies between about 18 kHz and 40 kHz, the ultrasonic motor further having a titanium wave guide in direct contact with the magnetic assembly, wherein the ultrasonic motor provides vibrational energy that can be transmitted through the wave guide and magnetic assembly directly to the tool insert where it is transformed to elliptical or flexural motion.

51. The method as recited in claim **50** wherein the wave guide is about ¼ the length of the tool insert and the displacement amplitude at the tip of the tool insert is about 100 microns peak-to-peak.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 6,227,853 B1
DATED : May 8, 2001
INVENTOR(S) : Thomas T. Hansen and Billy R. Flowers

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 19,
Line 26, delete "apparatus" and insert -- system --, therefor.
Line 27, delete "permanent magnet surrounds" and insert -- the one or more permanent magnets surround --, therefor.
Line 28, delete "is" and insert -- are --, therefor.
Line 30, delete "claim **11**" and insert -- claim **10** --, therefor.
Line 53, insert -- more -- between "one or" and "magnetic".

Column 20,
Line 52, delete "18." and insert -- 18 --, therefor.

Signed and Sealed this

Twenty-third Day of April, 2002

Attest:

JAMES E. ROGAN

Attesting Officer

Director of the United States Patent and Trademark Office